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Predator-Prey Interactions in The Dalles Dam Tailrace, 2002

Annual Report of Research for 2002

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Predation by northern pikeminnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieu*) has been documented as a significant source of mortality to outmigrating juvenile Chinook salmon (*Oncorhynchus tshawytscha*). We looked at the interaction between these predators and juvenile Chinook salmon in detail to describe areas within The Dalles Dam (TDA) tailrace where the risk of predation to outmigrating juvenile Chinook salmon is high. We used radio telemetry to evaluate the movement and behavior of 75 northern pikeminnow (NPM) and 75 smallmouth bass (SMB) within TDA tailrace from April to September, 2002. Predators were surgically implanted with radio transmitters and released within TDA tailrace between April 15 and June 7, 2002. In order to describe predator movements relative to juvenile salmon movements, radio-tagged juvenile Chinook salmon were released through the ice-trash sluiceway during the spring and summer outmigrations. Predator and prey fish were monitored using aerial tracking, boat tracking and fixed-site receiving stations. During the spring outmigration, 100 yearling Chinook salmon were released between May 9 and June 1, 2002. The median residence times of yearling Chinook salmon were 0.7 h (range 0.2 - 6.3 h) within the Boat Restricted Zone (BRZ; 7 km downriver of TDA) and 1.1 h (range 0.5 – 7.3 h) within the study area (from TDA to 1.7 km downstream) between May 9 and June 1, 2002. During the same period NPM were detected most often in the basin and BRZ island zones, accounting for 87% of the observations recorded during the spring season. Similarly, most SMB were detected in the basin island zone (58%). During the summer outmigration, 87 subyearling Chinook salmon were released between June 29 and July 21, 2002. The median residence times for subyearling Chinook salmon were 0.9 h (range 0.3 - 9.1 h) within the BRZ, and 1.2 h (range 0.6 – 9.4 h) within the study area between June 29 and July 21, 2002. During the summer outmigration, NPM used the BRZ and basin island zones in similar proportions (24% and 23%). The basin island zone accounted for the highest proportion of SMB observations during the summer (51%). Predation on yearling Chinook salmon (2%) was less than on subyearling Chinook salmon (7%). This difference is possibly due to the longer residence times, higher metabolic costs of predators, and greater size differential of predators and juvenile salmon during the summer outmigration period. Juvenile Chinook salmon released through the sluiceway would pass very near or through zones of high predator density during both outmigration periods. Radio-tagged NPM and SMB were associated with bedrock substrate (79% and 62%, respectively) in water characterized as low velocity, shallow, and near structure. Using these criteria, spatial models identified the basin and BRZ island zones as areas of high predator density that pose a high predation risk to

outmigrating juvenile Chinook salmon within TDA tailrace.

Introduction

Concern over declining numbers of anadromous salmon in the Columbia Basin has focused attention on predation as a major source of mortality. Rieman et al. (1991) and Vigg et al. (1991) have described northern pikeminnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieu*) as two major predators of outmigrating juvenile salmonids in the Columbia River Basin (CRB). Northern pikeminnow (NPM) is a native cyprinid widely distributed throughout the CRB and is considered a significant predator of juvenile salmonids (Rieman et al. 1991). Adult NPM range in size from 300 to 550 mm fork length (FL) and are considered to be opportunistic feeders, with fish > 200 mm FL being more piscivorous than smaller fish (Brown and Moyle 1981; Poe at al. 1991). Vigg et al. (1991) also observed that juvenile salmonids are a major dietary component of NPM > 250 mm FL. Zimmerman (1999) found that fish prey were the largest component of NPM diet and that 82.5% of identified fish were salmonids (maximum length 167mm). Petersen (2001) noted the dominance of salmonids as a prey item when present in gut contents and that larger NPM appeared more successful at capturing salmonids, and he suggested that NPM consumed salmonids during brief feeding bouts. Beamesderfer et al. (1996) observed that NPM might consume up to 8% of all juvenile salmonids during periods of outmigration. Collis et al. (1995) documented increases in the number of juvenile salmonids in NPM diet after hatchery releases, suggesting a response to prey density.

Smallmouth bass (SMB) are an introduced centrarchid now found throughout the CRB and are a source of mortality for outmigrating juvenile salmonids. Smallmouth bass are responsible for up to 7% of the total predation on juvenile salmonids in the John Day Reservoir (Rieman et al. 1991). Tabor et al. (1993) reported that SMB might be an important predator when wild subyearling Chinook salmon are abundant, usually in late spring/summer. He also suggested that high levels of salmonid predation by SMB in one area of the lower Columbia River was due to the size differential and habitat overlap of SMB and juvenile salmonids. Zimmerman (1999) observed that 14.2% of identified fish in the guts of SMB were salmonids (maximum length 167mm). Poe et al. (1991) suggested that size selective predation by SMB reflects the size-related vulnerability of salmonid prey in all seasons. Gray and Rondorf (1986) suggested that predation potential is high when juvenile salmonids occur in littoral areas that overlap with the preferred habitat of SMB. Zimmerman and Parker (1995) found relative densities of SMB in lower Columbia River impoundments to be intermediate between densities in the Snake River and the free flowing stretch of the Columbia River below Bonneville Dam. Smallmouth bass have also indirectly affected juvenile salmonid mortality rates. Poe et al. (1994) hypothesized that NPM predation on outmigrating salmonids has increased due to the introduction and subsequent proliferation of SMB resulting in competition for non-salmonid food resources.

Hydroelectric development has altered riverine conditions throughout the CRB and has affected the migrational behavior and survival of juvenile salmonids. Impoundments prolong migration, concentrate juvenile salmonids at dams and increase their susceptibility to predation (Ebel 1977; Raymond 1979, 1988; Mesa 1994). Beamesderfer and Rieman (1991), Rieman et al. (1991) and Ward et al. (1995) each separately concluded that the highest juvenile salmonid losses due to predation occurred in the lower Columbia River and near dams, especially the tailrace Boat Restricted Zones (BRZ). Petersen and Ward (1999) observed that predators in the tailrace of near-dam habitats consume a relatively high percentage of juvenile salmonids. Increased predation in these areas is possibly due to the effect hydroelectric developments have had in creating habitat favorable to predators. Poe et al. (1991) suggested that slow velocities and warmer temperatures in dam reservoirs of the Columbia River increased the available habitat for SMB. Faler et al. (1988) found that NPM prefer lower velocities. There are several low velocity backwater areas within 0.5 km of TDA. These backwaters as well as the rocky shores downstream of TDA could provide excellent habitat for NPM and SMB.

The objectives of this study were: describe the behavior and distribution of two important predators of juvenile salmon within The Dalles Dam (TDA) tailrace, and describe the risk of predation to juvenile Chinook salmon. These data were used to identify specific areas where predation risk is highest. Although previous studies have looked at distributions of fish within the CRB, and several have looked at NPM behavior and distribution with regard to predator-prey interactions at this scale, few have reported these data for SMB. This study used radio-tagged yearling and subyearling Chinook salmon (*Oncorhynchus tshawytscha*) released into the sluiceway of TDA as potential prey for the radio-tagged predators.

Methods

The Dalles Dam is a hydroelectric facility located at river kilometer (rkm) 308 of the Columbia River. Operated by the U.S. Army Corps of Engineers, the dam extends 2.4 km from the powerhouse on the Oregon shore to the navigation lock on the Washington shore (Figure 1). The Dalles Dam is the only dam on the lower Columbia River that lacks a screened juvenile bypass system (JBS). Three possible passage routes through the dam are the powerhouse, the spillway, and the ice-trash sluiceway. Currently, the sluiceway is operated as an *ad hoc* JBS.

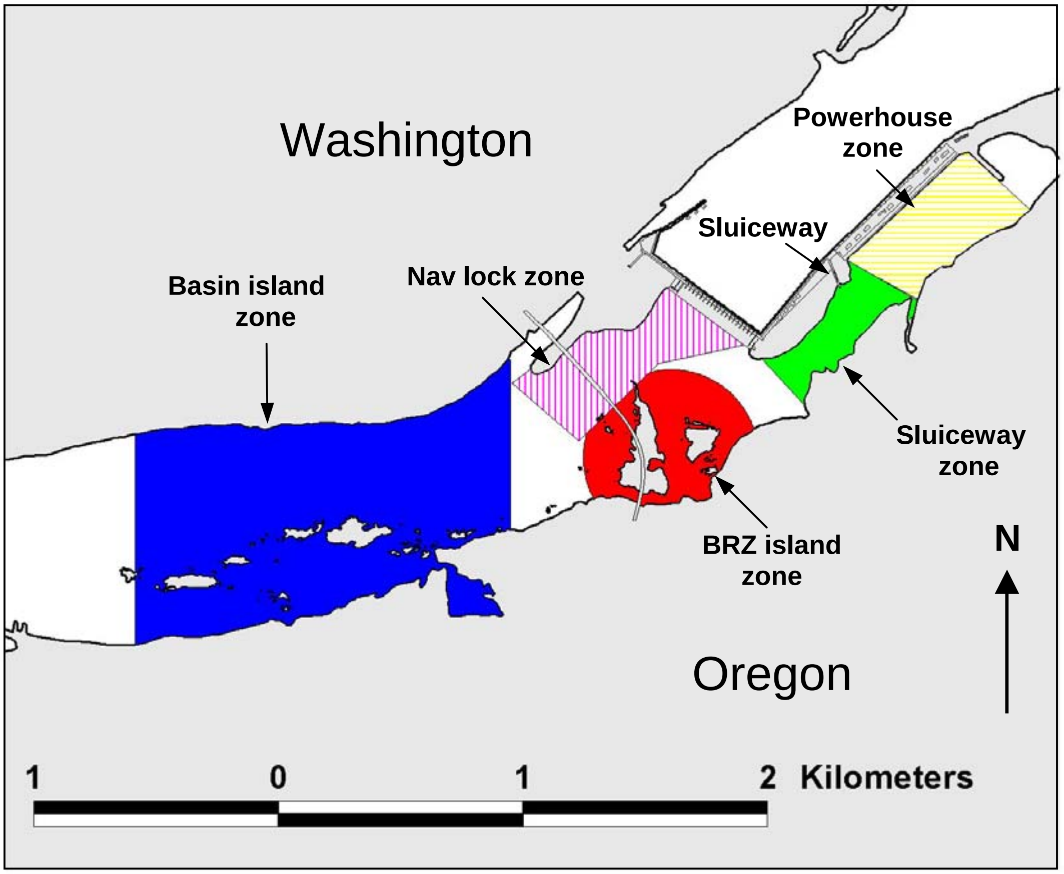


Figure 1. Locations of detection zones in The Dalles Dam tailrace, 2002. Zones are based on the area of detection of fixed site receiving stations placed throughout The Dalles Dam tailrace.

Northern pikeminnow and SMB were collected through angling and electroshocking efforts within TDA tailrace between April 15 and June 7, 2002. Of the 75 NPM collected by angling, 68 came from TDA tailrace and the remainder were from TDA pool. Smallmouth bass were collected from TDA tailrace by angling (one) or electroshocking (74). A radio transmitter, 11mm x 43mm, 7g (in air), was intraperitoneally implanted in each fish following procedures of Isaak and Bjorn (1996) and Martinelli and Shively (1997). The fish were allowed to recover from handling and were then released into the tailrace. All fish were allowed a 7 d recovery period before data was collected. During the study, anglers caught ten radio-tagged predators, causing small reductions in both NPM (3) and SMB (7).

Juvenile salmonids were collected at the John Day Dam Smolt Monitoring Facility and held 6-12 h before being transported to the tag site at TDA. Radio transmitters used in yearling Chinook salmon (CH1) were 7.3 mm x 18 mm and weighed 1.4 g in air. Subyearling Chinook salmon (CH0) were implanted with transmitters that were 6 mm x 15 mm and weighed 0.9 g in air. Transmitters were gastrically implanted into fish following procedures of

Martinelli et al. (1998). Tagged fish were held in a 0.8 m diameter tank for approximately 24 h prior to release. All juveniles were released through the ice-trash sluiceway using 4" flexible hose. Juveniles were tracked within the BRZ by boat and fixed-site receiving stations.

A primary concern was collecting accurate locations of fish. Boat tracking was used to collect fine-scale locations of radio-tagged fish in the Columbia River Basin from Bonneville (rkm 235) to John Day (rkm 347) dams. Two boats were used, with each boat tracking 40 – 48 h per week from April to September, 2002. Boat tracking efforts were focused in the TDA tailrace. Boat tracking efforts collected fine-scale data by detecting a fish at close range (0 – 30 m) using an underwater antenna, then recording the boat's location using a Global Positioning System (GPS). The GPS data was real-time and manually corrected prior to importing the data into a Geographic Information System (GIS). Additionally, aerial tracking along the Columbia River Basin from Bonneville to John Day dams, including tributaries such as the White Salmon, Klickitat, and Deschutes rivers provided additional course-scale GPS data. Aerial tracking was conducted every two weeks. Aerial data allowed us to cover a greater area than boats alone and allowed us to identify fish that had left the study area. Mobile data refers to the combined data collected via aerial and boat tracking.

We wanted to describe the habitat preferences of radio-tagged NPM and SMB located within the study area; therefore, habitat data was assigned to boat data using GIS and SAS software (SAS Institute 2000). Given that a small number of locations existed per species, we pooled location data as per Neu *et al.* (1974). The frequency distributions of water velocity, depth, distance to structure and distance to macrophyte associated with NPM and SMB locations were non-normal (Shapiro-Wilk tests $P \leq 0.001$); therefore, we tested medians using the Wilcoxon scores. A chi-square test (χ^2) for goodness-of-fit was used to determine statistical significance of habitat use. The χ^2 test compared the number of fish locations over a given substrate to the availability of that substrate (Alldredge and Ratti 1986). Bonferroni confidence intervals were calculated for association with each substrate type. The availability or area of each substrate was determined with GIS. The maximum likelihood (G^2) statistic is presented for comparison to the χ^2 statistic. Pacific Northwest National Laboratory (PNNL) provided tailrace model data of bathymetry, substrate type, and velocity. Bathymetry and velocity data were provided at four turbine discharge levels (100 kcfs, 150 kcfs, 200 kcfs and 250 kcfs). Model data provided by PNNL was not available for all fish locations; therefore, some locations were not used in several analyses. Macrophyte data was collected by the USGS during 2001, a low flow year. Distances to the nearest structure and macrophyte, defined as the shortest straight-line distance from the predator to the nearest shore, structure or vegetation, were calculated with the GIS.

Fixed-site receiving stations (fixed stations) continuously monitored the general movements of radio-tagged NPM, SMB, and juvenile salmonids in the TDA study area (Figure 1) from April to September, 2002. They extended from the dam to approximately 3 km downstream to the Port of The Dalles. We defined five study zones in the study area (Figure 1) to describe fish movements in TDA tailrace. Zone perimeters were established based on the location and range of detection of the fixed stations. Predator data collected by fixed stations were compressed for analysis. Radio-tagged fish were assigned to zones on an hourly basis established by the data collected by each receiver during each hour of the day. Thus, each fish was designated a zone for up to 24 h each day and movements by zone could be tracked on an hourly basis. Each zone was assigned GPS coordinates that corresponded to the center of the zone to allow for the calculation of movement distances. Boat data was considered more accurate than receiver data; therefore, the boat data was preferentially used in situations where boat and receiver data occurred within the same hour of the day. Movements were characterized by interzone movements, directional movements, and travel rates. Travel distances from the study area were calculated from the downstream or upstream edge of the study area to each recorded location downstream or upstream. We defined two movement categories to derive fine-scale information: short distance movements and long distance movements. Short distance movements were less than 2 km and long distance movements were greater than 2 km.

Residence time data was a primary variable of interest in analysis of juvenile outmigrations. Exit sites for the calculation of residence times were established using fixed stations within the BRZ (BRZ exit, 0.7 km downriver of the dam) and the basin island zone (basin exit, 1.7 km downriver of the dam). Boat Restricted Zone residence times (in hours, h) were calculated from the time of release to the last detection recorded by fixed stations located in the navigation lock or the BRZ island zones. Residence time within the study area was determined from time of release to the last detection within the basin island zone. These calculations result in cumulative residence times, i.e., residence time in the basin island zone includes residence time in the BRZ. The frequency distribution of residence time data were non-normal, therefore medians were compared using Wilcoxon scores (day/night comparisons) and Tukey's studentized range test (multiple comparisons). Throughout this report, statistical findings were reported as significant when $P \leq 0.05$. All statistical analyses were run using SAS software.

Boat tracking and fixed stations allowed us to quantify suspected predation events on juvenile Chinook salmon. Piscivorous predation was suspected when a fish was detected 24 h post release via fixed stations or boat tracking within the study area. Continuous fixed station detection of a radio-tagged juvenile Chinook salmon over a period of days provided support for a predation event. Juvenile Chinook salmon located via boat tracking upstream of the release site also supported the predation event. Fixed station or boat data demonstrating juvenile Chinook salmon movement consistent with predator behavior in TDA tailrace (Martinelli and Shively 1997) provided a final confirmation that a predation event occurred. However, we were not able to determine where or when the event took place. Avian predation events were suspected when a single radio-tagged juvenile was detected by several fixed stations simultaneously. There were no avian predation events recorded during this study.

Results

Summary Findings

A total of 150 predators were radio-tagged and released within TDA tailrace (Table 1). Between May 3 and June 7, 2002, 75 radio-tagged NPM were released. Northern pikeminnow had a mean fork length of 370.8 mm and a mean weight of 793.8 g. Between April 15 and May 11, 2002, 75 SMB were released within TDA tailrace. Smallmouth bass had a mean fork length of 352.8 mm and a mean weight of 839.0 g. The tag weight to body weight ratio (TWBW) of SMB and NPM was 0.92% and 0.97%. One hundred radio-tagged CH1 were released from the sluiceway during the spring outmigration (May 9 to June 1, 2002). Yearling Chinook salmon had a mean fork length of 152.4 mm and mean weight was 33.9 g. The TWBW of CH1 was 4.1%. During the summer outmigration (June 29 to July 21, 2002) a total of 87 radio-tagged CH0 were released from the sluiceway at TDA. Sub-yearling Chinook had a mean fork length of 118.0 mm and mean weight was 17.2 g. The TWBW of CH0 was 5.3%.

Table 1. Fork lengths and weights of radio-tagged study fish released at The Dalles Dam, 2002. Smallmouth bass (SMB) and northern pikeminnow (NPM) were released in The Dalles Dam tailrace. Yearling (CH1) and subyearling (CH0) Chinook salmon were released from the ice-trash sluiceway during spring and summer study periods. Measurements were made prior to tagging.

Species	N	Fork length (mm)				Weight (g)			
		Median	Mean	SE	Range	Median	Mean	SE	Range
SMB	75	345.0	352.8	3.9	310.0 – 485.0	768.0	839.0	39.6	450.0 – 2465.0
NPM	75	360.0	370.8	5.0	315.0 – 500.0	670.0	793.8	41.7	400.0 – 2200.0
CH1	100	149.0	152.4	1.7	119.0 – 207.0	30.4	33.9	1.3	16.0 – 83.7
CH0	87	115.0	118.0	0.9	109.0 – 147.0	15.5	17.2	0.5	13.0 – 32.9

Detection of radio-tagged CH1 (95, 95%) and CH0 (84, 97%) was high (Table 2). Overall, fixed stations detected more CH1 (86, 86%) than did boat tracking efforts (64, 64%). Similarly, fixed station detections of CH0 (81, 93%) were greater than boat tracking efforts (65, 75%). We detected 71 (95%) of the NPM during the study (Table 2). During the study periods, detections of NPM by fixed stations were generally similar to boat tracking efforts, while aerial tracking efforts were less successful. Overall, NPM detections via fixed stations (65, 87%) and boat tracking (65, 87%) were higher than aerial tracking efforts (34, 45%). More NPM were detected during the summer study period (66, 88%) than spring (57, 76%) or post (30, 40%) study periods. We detected 73 (97%) of the SMB overall (Table 2). Boat tracking efforts detected 72 (96%) SMB, more than either fixed stations (66, 88%) or aerial tracking efforts (44, 59%). More SMB were detected during the spring (73, 97%) than in summer (61, 81%), or post (47, 63%) study periods.

Table 2. Number of individual radio-tagged northern pikeminnow (NPM), smallmouth bass (SMB), yearling Chinook salmon (CH1), and subyearling Chinook salmon (CH0) detected in the Columbia River and its major tributaries between the mouth of the John Day River and Bonneville Dam, 2002. Yearling and subyearling Chinook salmon were released during spring and summer study periods, respectively. The number of locations is summarized by period and method.

Species	Study period	Detection method			
		Aerial (%)	Boat (%)	Fixed (%)	All (%)
CH1	Spring	–	64 (64)	86 (86)	95 (95)
CH0	Summer	–	65 (75)	81 (93)	84 (97)
NPM	Spring	10 (13)	41 (55)	53 (71)	57 (76)
	Summer	24 (32)	57 (76)	56 (75)	66 (88)
	Post	5 (7)	21 (28)	20 (27)	30 (40)
	Overall	34 (45)	65 (87)	65 (87)	71 (95)
SMB	Spring	18 (24)	71 (95)	65 (87)	73 (97)
	Summer	29 (39)	56 (75)	46 (61)	61 (81)
	Post	18 (24)	40 (53)	24 (32)	47 (63)
	Overall	43 (57)	72 (96)	66 (88)	73 (97)

The detection frequency of NPM and SMB in relation to the water temperature and passage of prey items is shown in Figure 2. Data was not collected on NPM until May 10, 2002. The number of detections of NPM within TDA remained nearly constant until early July, when fish began to move away from the study area. Smallmouth bass began leaving the study area as early as May. Total discharge ranged from 86.6 to 466.5 kcfs between April 25 and August 31, 2002.

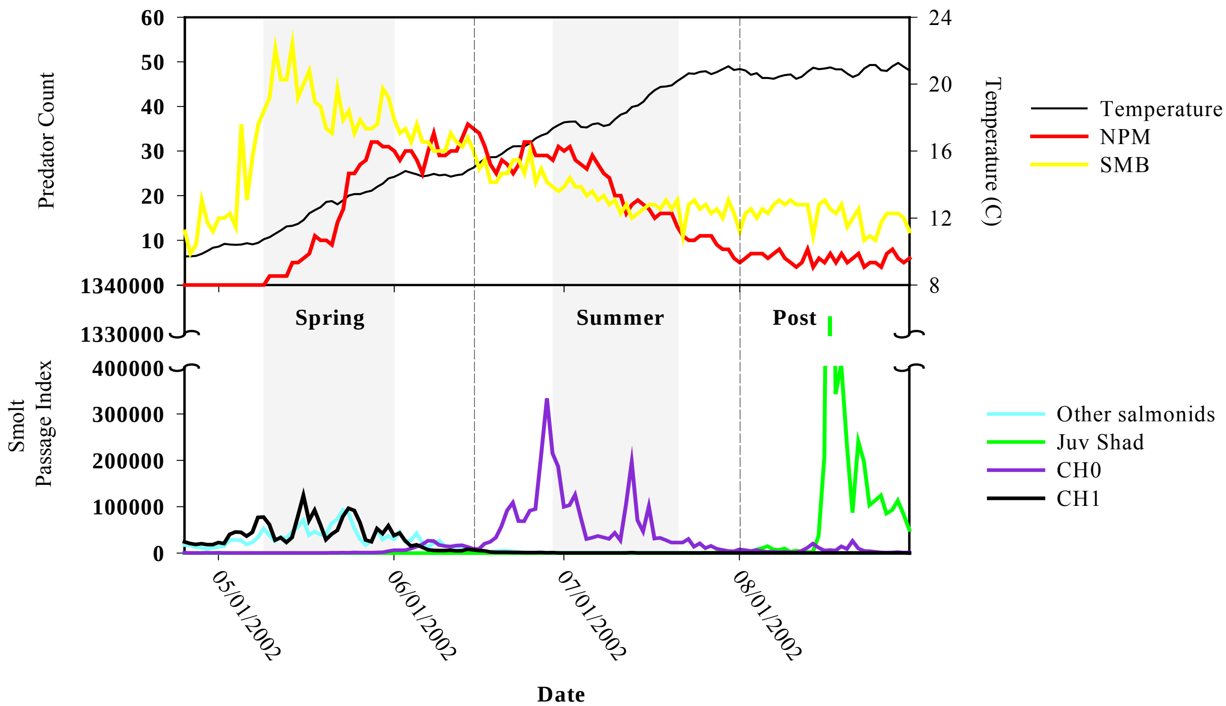


Figure 2. The top graph represents the abundance of radio-tagged northern pikeminnow (NPM) and smallmouth bass (SMB) located via boat tracking and fixed gear detection in The Dalles Dam tailrace, 2002. The temperature, in °C, is also plotted on the graph. The bottom graph represents the smolt passage index for yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), juvenile shad, and other salmonids (juvenile sockeye, coho, and steelhead) at the Smolt Monitoring Facility (SMF) at John Day Dam. Shaded areas represent CH1 and CH0 release periods. The dotted lines demarcate study periods. Smolt index data were acquired from the Fish Passage Center web page at www.fpc.org as well as from the SMF.

Northern Pikeminnow

During the study period, 65 (87%) NPM were detected in the study area. These fish averaged 30.0 days (range: 1 d – 101 d) within the study area. Six radio-tagged NPM were detected within the study area at the end of the study (Figure 2). We identified 44 (59%) NPM outside of the study area. Northern pikeminnow traveled downstream as far as Cascade Locks, OR (rkm 238) and as far upstream as John Day Dam (rkm 347, Figure 3). Nine (20%) of the fish that left returned to the study area (Table 3). Before returning, most of the fish traveled downstream of TDA at least 14 km away from the study area and returned to TDA within 6.3 to 30.3 days.

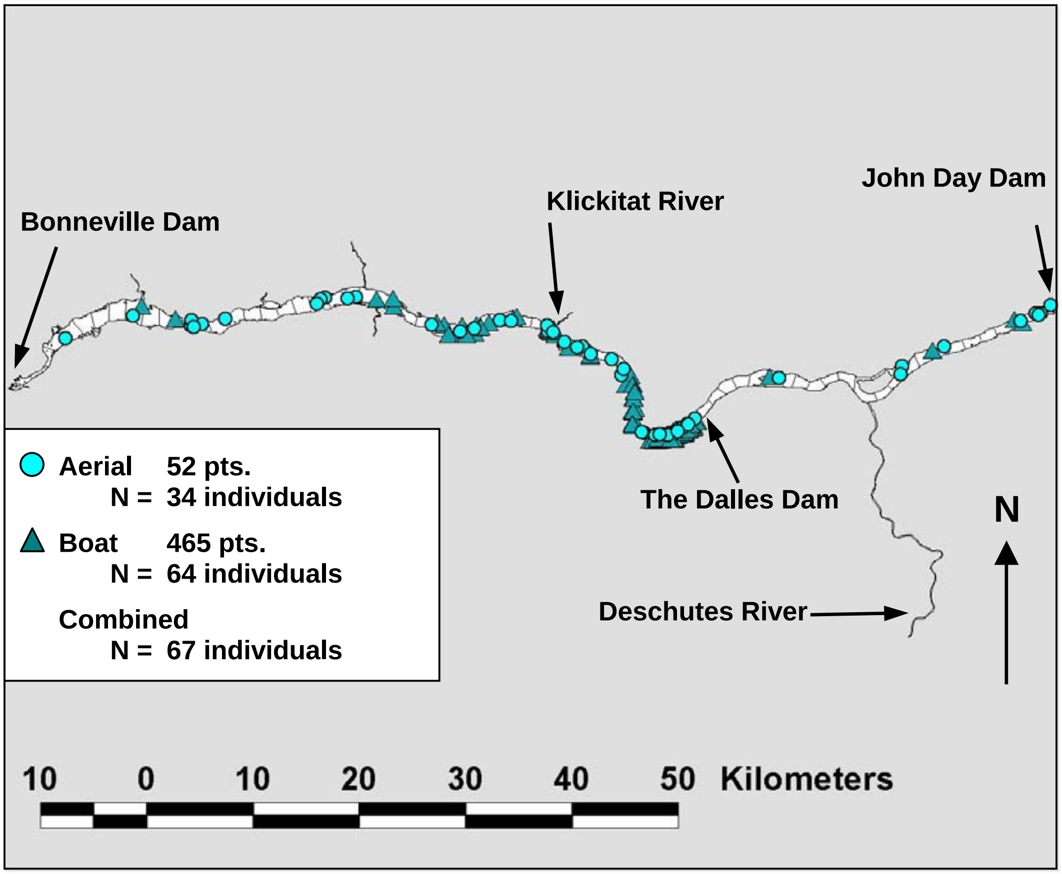


Figure 3. Locations of radio-tagged northern pikeminnow (NPM) in the Columbia River and major tributaries between Bonneville and John Day dams, 2002. NPM were released at various sites in The Dalles Dam tailrace. Each point represents a fish location collected via aerial or boat tracking.

Table 3. Radio-tagged northern pikeminnow (NPM) returning to The Dalles Dam tailrace, 2002. Location indicates the farthest detection from the tailrace during each event.

NPM ID	Location	Distance (km)	Days
54196	Mosier	19.3	7.8
54202	Lyle	15.6	6.3
60186	Downstream	8.6	10.5
60195	Downstream	7.8	12.3
60196	Lyle	14.4	15.9
61195	Lyle	14.5	19.7
61200	Biggs	25.9	30.3
61210	Wind Mountain	45.9	20.3
62200	Lyle	14.3	8.1

Boat tracking detections of NPM within the study area are presented in Figure 4. Detections were concentrated in a few areas, in particular the basin and BRZ island zones were areas of heavy use. The detection frequencies within each zone by hour during the study periods are presented in Figure 5. Northern pikeminnow were most frequently detected in the basin and BRZ island zones during the all three study periods (Figure 5). This pattern was most dominant during the spring period, when over 80% of detections occurred within the two island zones. However, NPM detections in these zones decreased during the summer period as the navlock, sluiceway, and powerhouse zones were more frequently used. The detection frequencies within the basin island and powerhouse zones during the post migration period were similar to those observed during the spring outmigration period, but basin island detections remained near summer outmigration period levels. The detection frequencies of NPM within the navlock and sluiceway zones increased to the highest levels during the post migration period. The frequency of zone use was similar regardless of time of day during all three study periods. Boat tracking detections by study period are presented in Figure 6. Northern pikeminnow locations during day and night are presented in Figure 7.

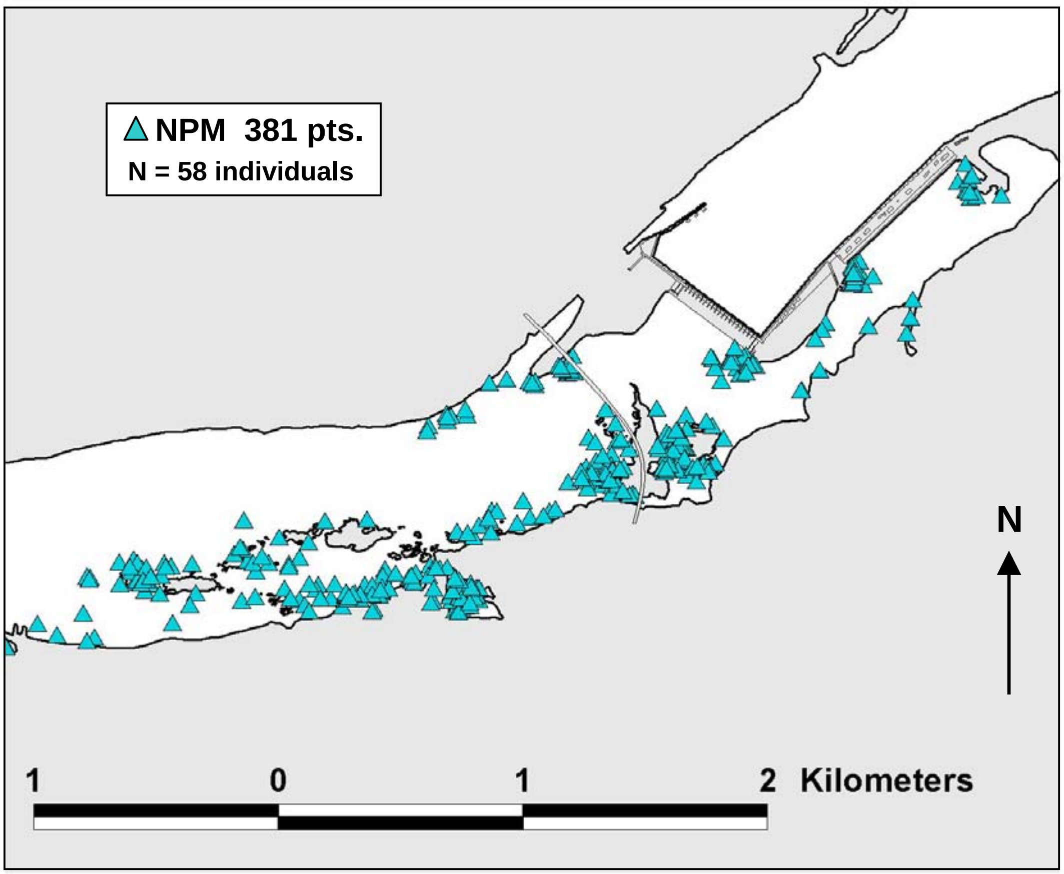


Figure 4. Locations of radio-tagged northern pikeminnow (NPM) in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking over the entire season.

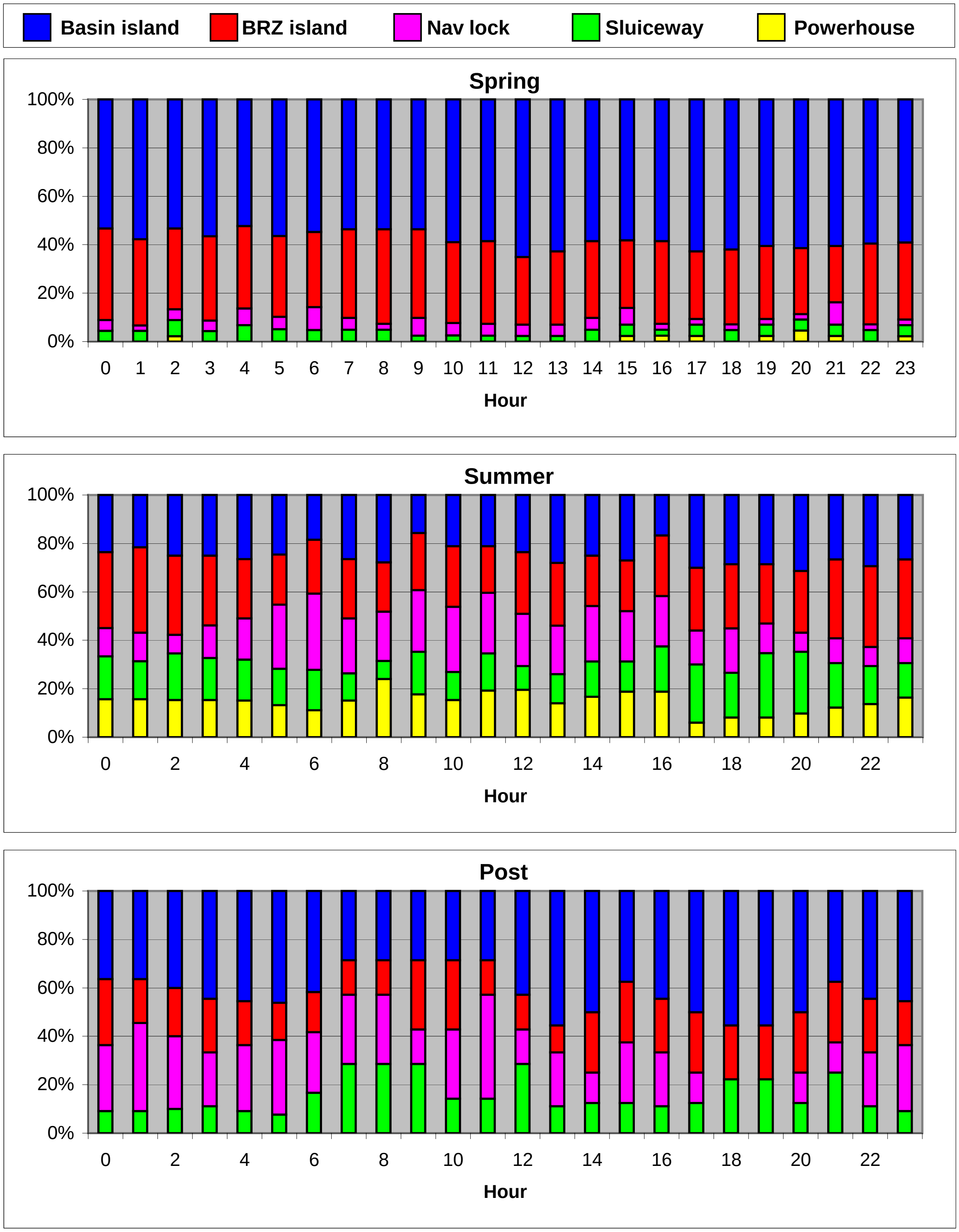


Figure 5. Observations of radio-tagged northern pikeminnow (NPM) in The Dalles Dam tailrace during spring, summer, and post migration study periods, 2002. An observation represents the presence of an individual fish in a detection zone during an hour block. Each hour bar displays the percentage of total observations in each zone.

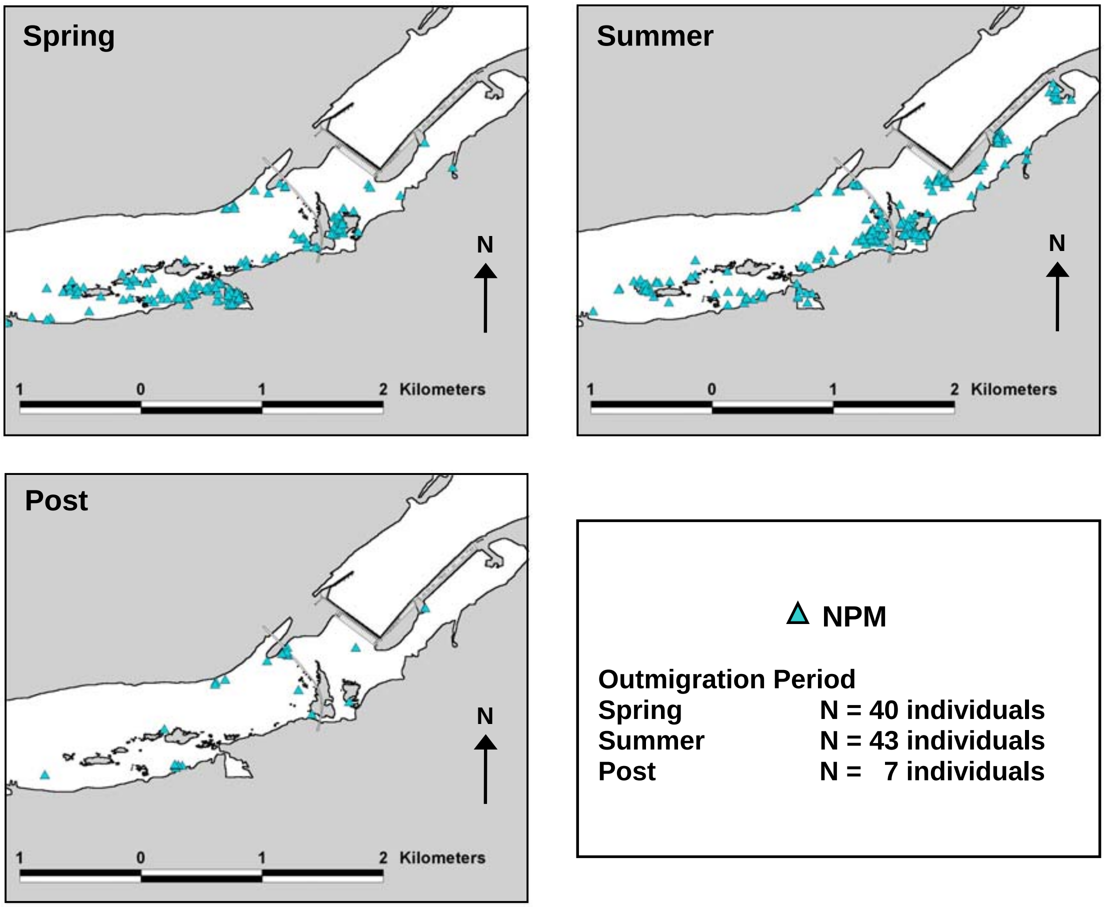


Figure 6. Locations of radio-tagged northern pikeminnow (NPM) in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during spring, summer, or post outmigration study periods. Fish were monitored over multiple study periods. N represents the number of individual fish located. Spring locations in the tailrace total 57 points, representing 27 individuals. Summer locations in the tailrace total 97 points, representing 31 individuals. Locations in the tailrace total 27 points, representing seven individuals during the post migration period.

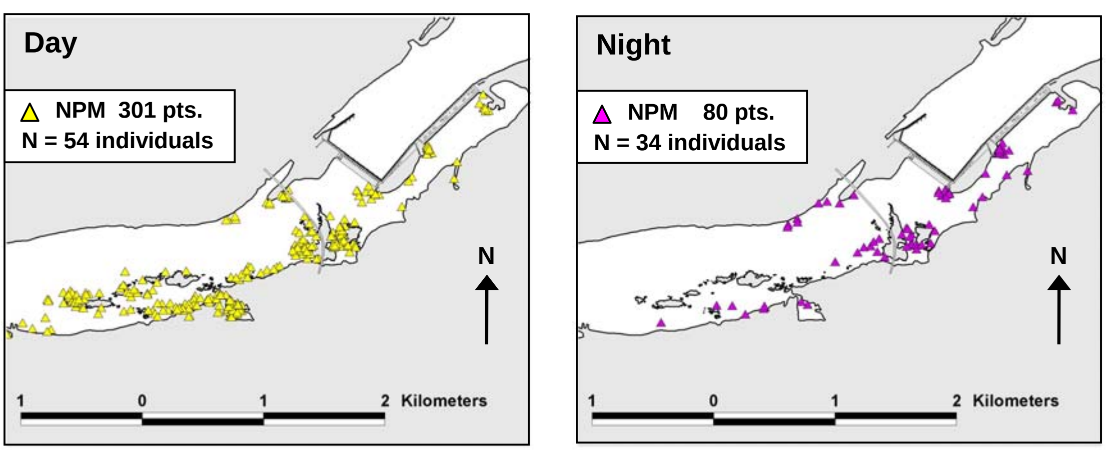


Figure 7. Locations of radio-tagged northern pikeminnow (NPM) in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during either day or night.

Depths, velocities, and distances to structures and macrophytes corresponding to NPM location data during four turbine discharges and study periods are presented in Table 4. The median depth at fish location was 3.05 m (range 0.30 - 59.7 m). Median water velocity was 24.38 cm/s (range 0.00 - 237.7 cm/s). The median distance to a structure was 23.83 m (range 0.19 – 146.7 m). The median distance to macrophytes was 41.81 (range 0.34 – 600.7). Median depths and distances to structures were not significantly different within turbine discharge or study period (Table 4). Median water velocities at NPM locations were significantly different within turbine discharge ($P < 0.0005$) and study period ($P < 0.0001$; Table 4). Median distances to macrophytes were significantly different within turbine discharge ($P < 0.0001$) and study period ($P < 0.0003$; Table 4). The bathymetry of the study area during the turbine discharge of 250 kcfs with associated NPM locations is presented in Figure 8. Velocities and NPM locations during the different turbine discharge conditions are presented in Figures 9 - 12.

Table 4. Depth, distance, and water velocity data assigned to radio-tagged northern pikeminnow (NPM) locations in The Dalles Dam tailrace, 2002. Data is grouped by turbine discharge condition (TD) and study period (SP). Geographic Information System coverages were used to assign fish locations to river depth, water velocity, and distance data. Hydraulic modeling coverages of river depth and water velocity for 100, 150, 200, and 250 kcfs turbine discharge conditions were created by Pacific Northwest National Laboratory. Macrophyte coverage was mapped during a low flow year, 2001. An asterisk indicates medians between turbine discharge conditions or outmigration periods are significantly different.

TD (kcfs) SP	N	River depth (m)				Water velocity (cm/s)			
		Median	Mean	SE	Range	Median	Mean	SE	Range
100	48	3.35	3.89	0.40	0.30-13.7	15.24*	33.27	5.37	0.00-125.0
150	72	3.05	7.26	1.35	0.61-59.7	19.81*	39.24	6.63	0.00-179.8
200	61	2.74	4.89	1.09	1.22-54.9	18.29*	41.02	6.71	6.10-210.3
250	73	2.74	4.27	0.42	0.91-14.3	33.53*	50.94	5.80	3.05-237.7
Spring	70	3.05	5.78	1.13	0.30-54.9	12.19*	27.61	4.92	0.00-204.2
Summer	165	2.74	5.00	0.58	0.61-59.7	30.48*	48.62	3.89	0.00-237.7
Post	20	3.81	4.77	0.74	0.91-13.7	24.38*	36.88	9.53	0.00-125.0
Overall	254	3.05	5.20	0.49	0.30-59.7	24.38	47.90	3.00	0.00-237.7

TD (kcfs) SP	N	Distance to structure (m)				Distance to macrophytes (m)			
		Median	Mean	SE	Range	Median	Mean	SE	Range
100	48	25.42	29.31	2.77	2.06-77.8	133.49*	180.93	25.34	4.26-586.3
150	73	18.01	27.92	3.07	0.19-146.7	97.81*	152.73	17.89	0.52-600.7
200	61	24.98	34.33	3.86	3.24-134.4	17.11*	83.63	17.84	0.34-569.8
250	73	22.86	25.83	2.48	0.63-122.6	14.68*	73.60	15.56	0.54-575.2
Spring	70	26.15	31.38	3.11	1.43-134.4	18.28*	50.83	8.08	0.49-384.4
Summer	165	21.78	28.36	1.96	0.19-146.7	75.26*	149.78	13.61	0.34-600.7
Post	20	27.43	27.45	3.63	2.06-51.88	94.72*	101.83	25.59	4.26-390.4
Overall	255	23.83	29.12	1.55	0.19-146.7	41.18	118.86	9.67	0.34-600.7

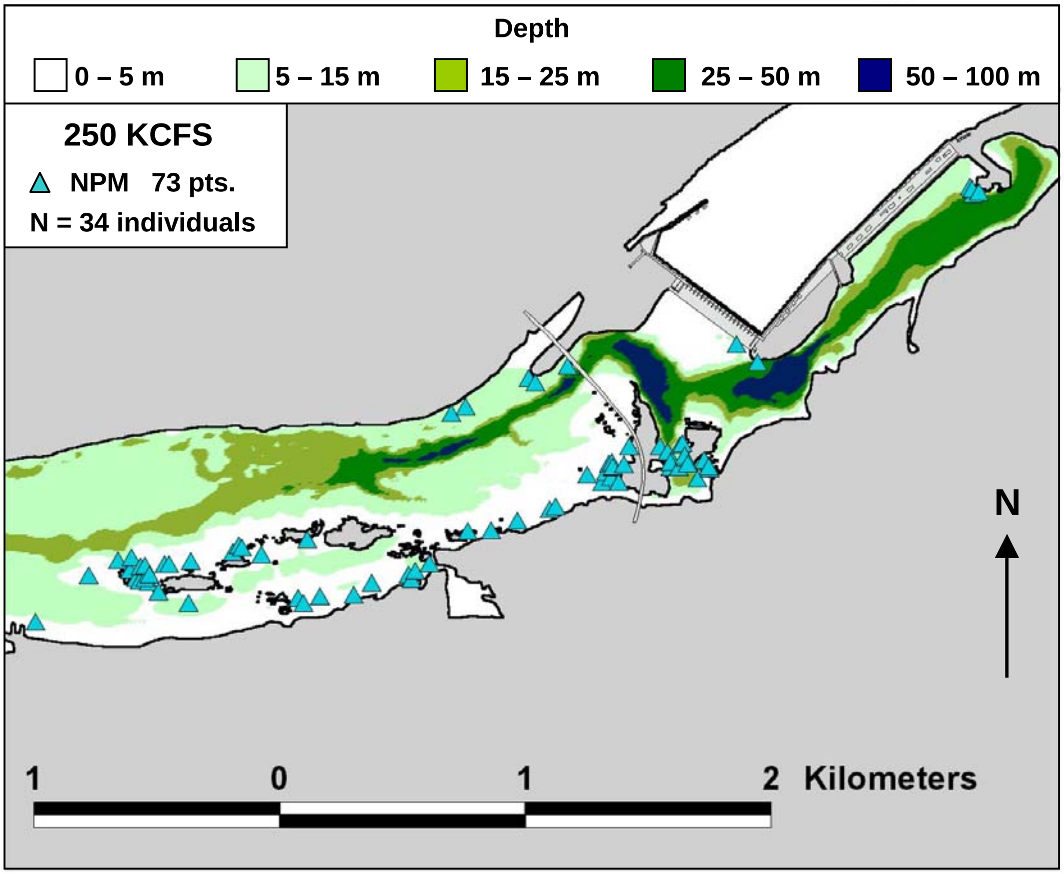


Figure 8. Locations of radio-tagged northern pikeminnow (NPM) and river depths in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 250 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

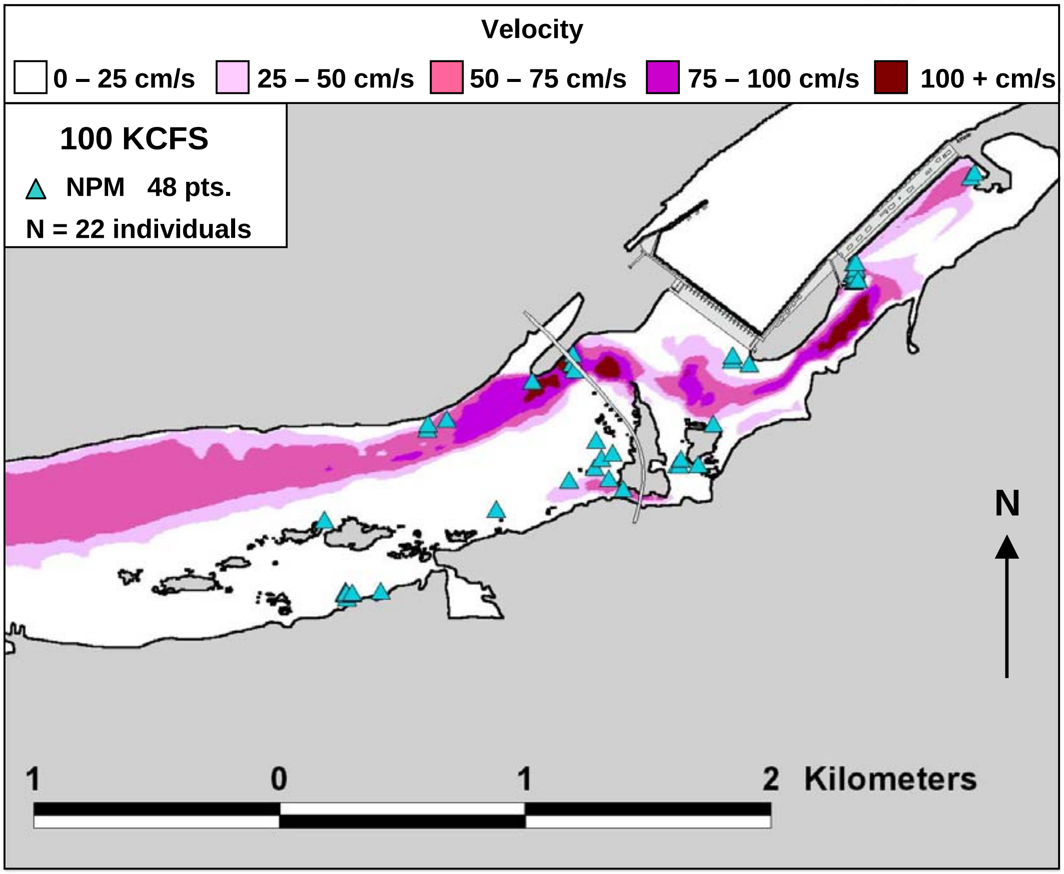


Figure 9. Locations of radio-tagged northern pikeminnow (NPM) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 100 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

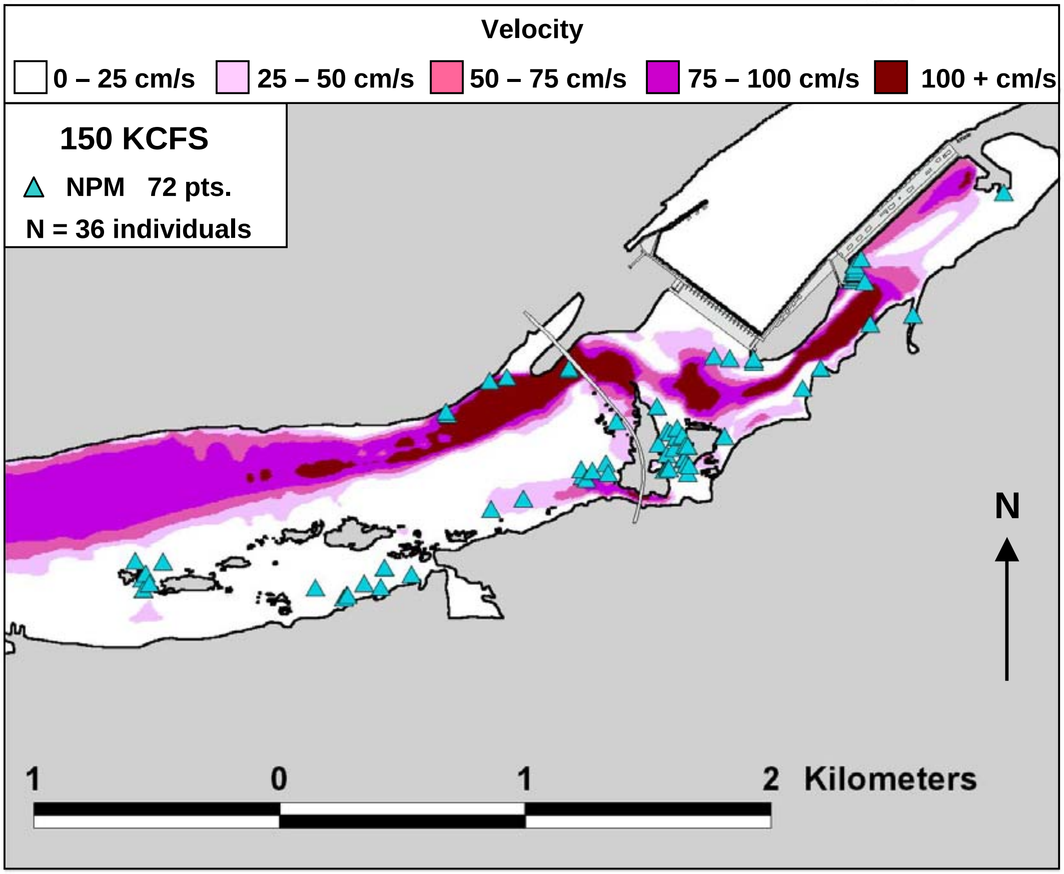


Figure 10. Locations of radio-tagged northern pikeminnow (NPM) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 150 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

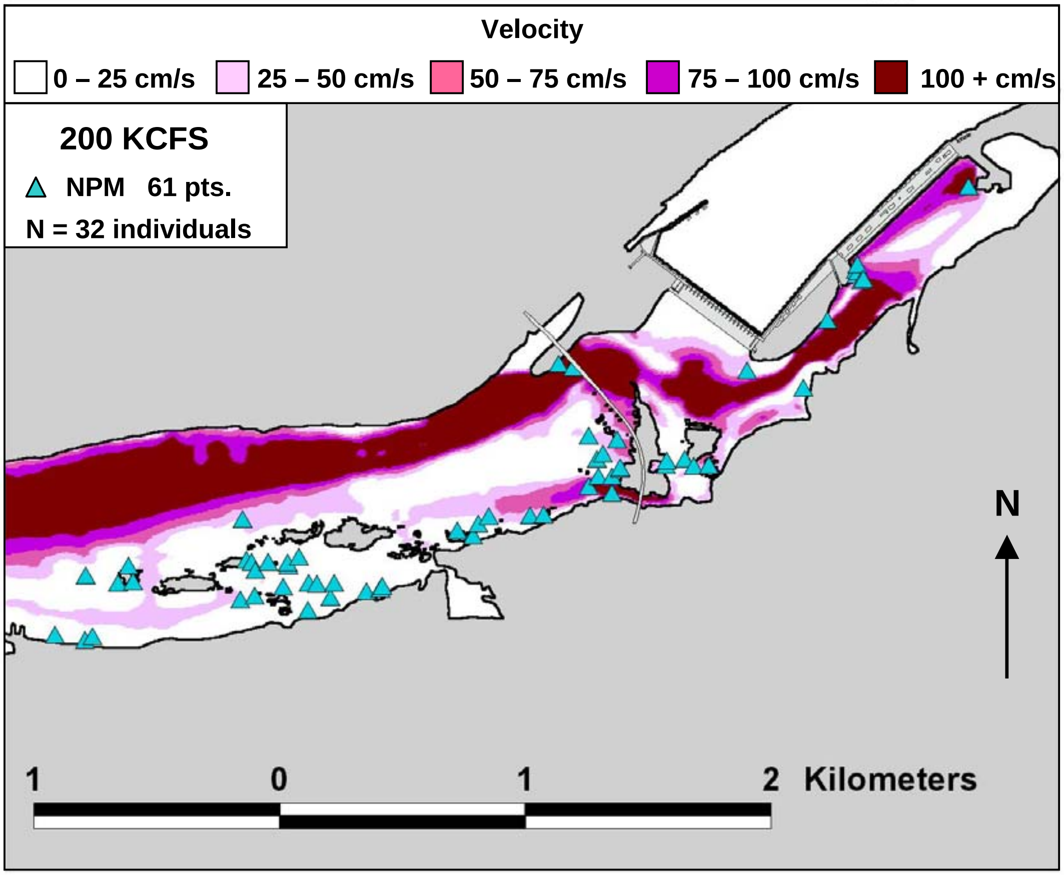


Figure 11. Locations of radio-tagged northern pikeminnow (NPM) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 200 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

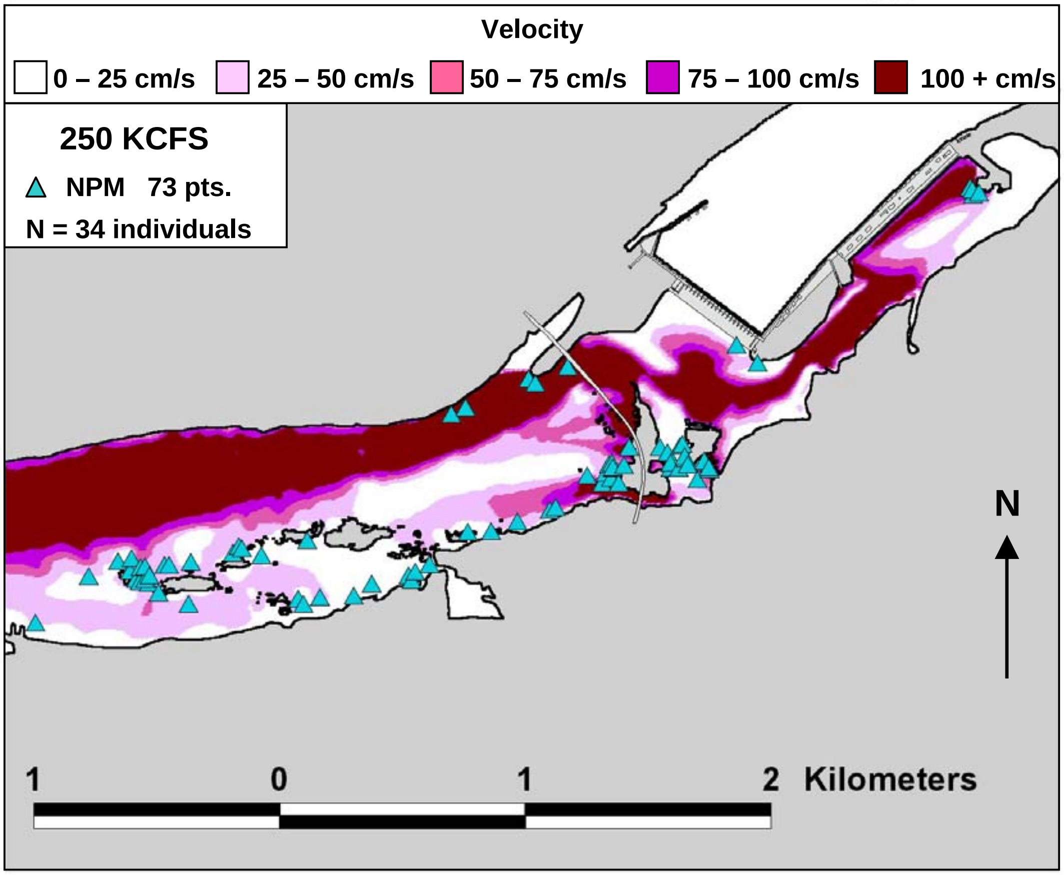


Figure 12. Locations of radio-tagged northern pikeminnow (NPM) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 250 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

Generally, NPM movements were classified as short distance (98.6%). Data reveals that individual fish did not stay within the confines of one zone. Individual NPM generally moved between zones about twice per day (Figure 13). Travel rates and upstream/downstream movements are presented in Figure 14. Downstream and upstream movements were similar within each study period, while most movements occurred during the summer study period. Short distance movements were dependent upon study period, with more downstream (χ^2 = 1221.79, P < 0.0001) and upstream (χ^2 = 1288.48, P < 0.0001) movements occurring during the summer. Most short distance movements were less than 0.6 km/h (65.7%). Long distance movements were also dependent upon study period. Most downstream (χ^2 = 31.24, P < 0.0001) and upstream movements (χ^2 = 32.58, P < 0.0001) occurred during the summer. Sixty one percent of the long distance movements had a travel rate of 0.2 km/h or less. Figures 15 - 18 show examples of travel paths of radio-tagged NPM.

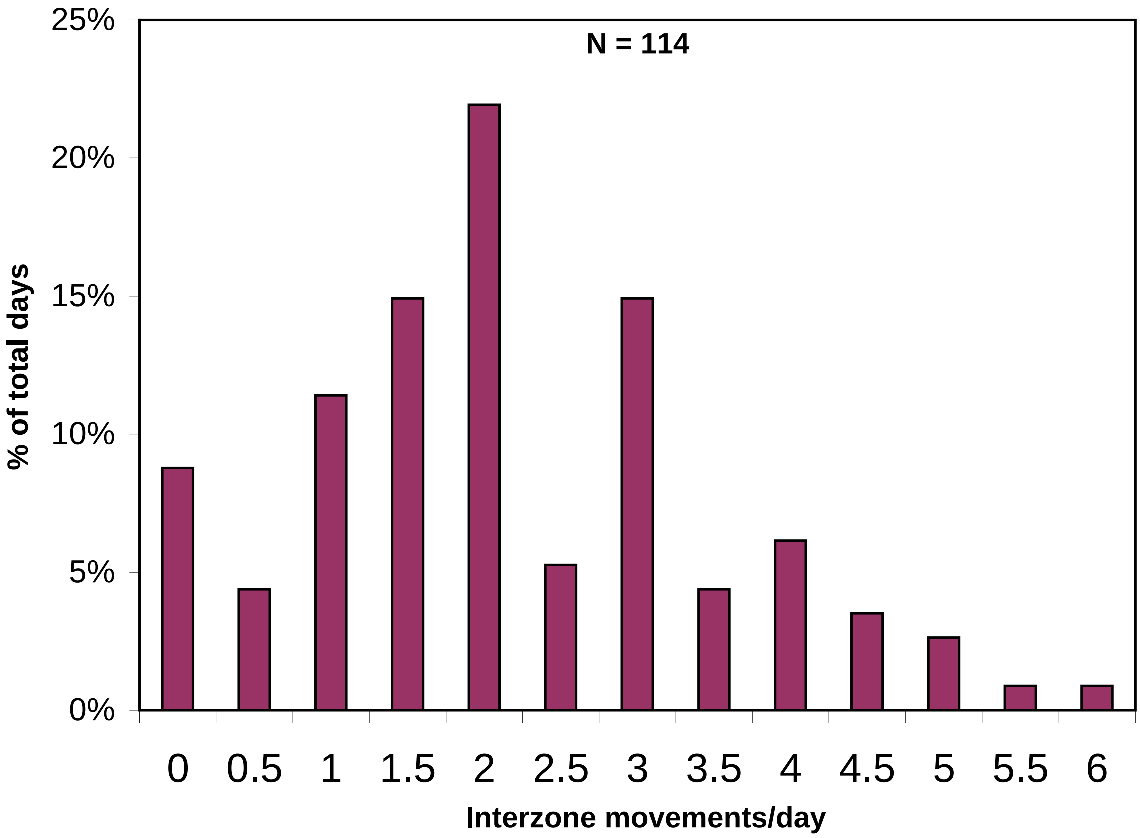


Figure 13. Average daily movement between detection zones by radio-tagged northern pikeminnow (NPM) in The Dalles Dam tailrace, 2002. Detection zones were determined using fixed gear detection and boat locations. Interzone movements were calculated by summing NPM daily movements and dividing by the total number of fish detected that day.

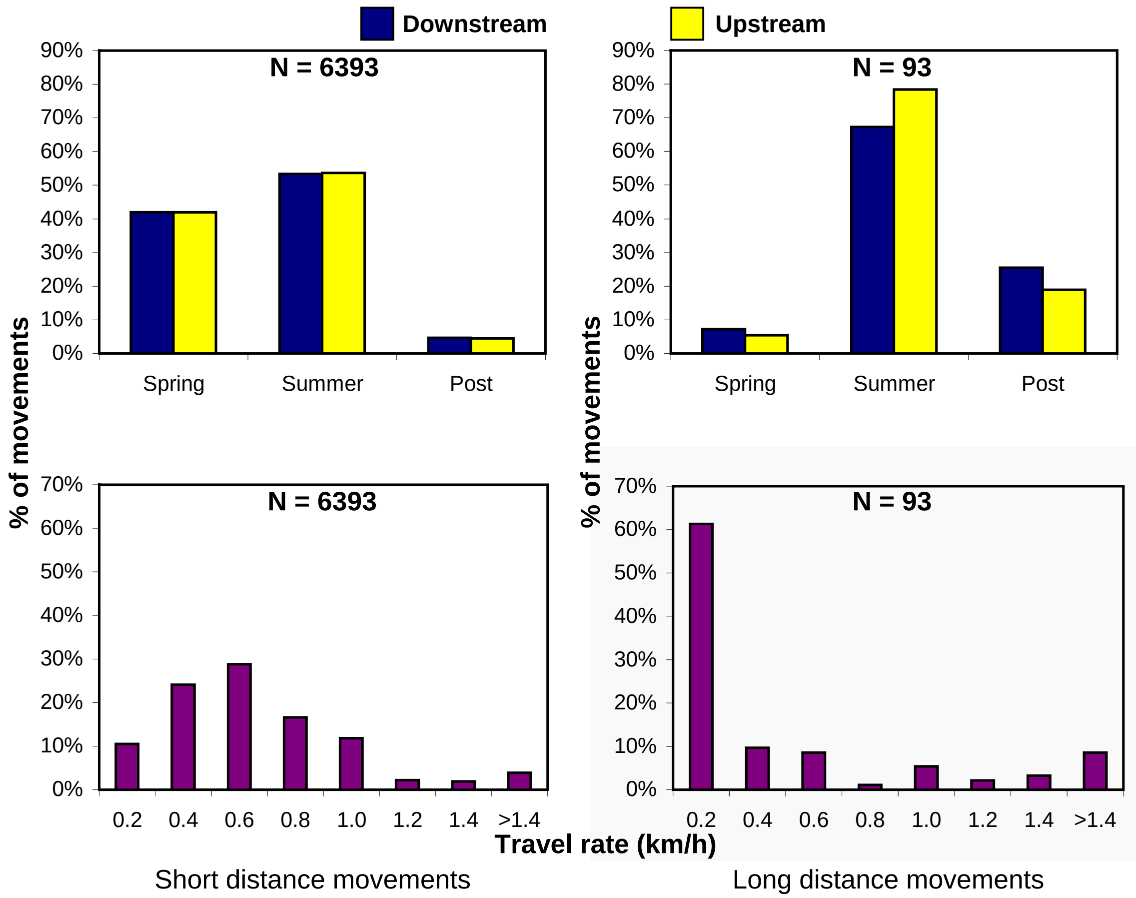


Figure 14. Direction and rate of movement of radio-tagged northern pikeminnow (NPM) in the Columbia River, 2002. Movements are classified as short distance if fish locations were successively made within 2 km of each other and long distance if successive locations were greater than 2 km apart. Travel rates and directional movements were determined using fixed station detections, boat locations, and aerial locations. Each movement was given a travel rate based upon distance traveled and travel time.

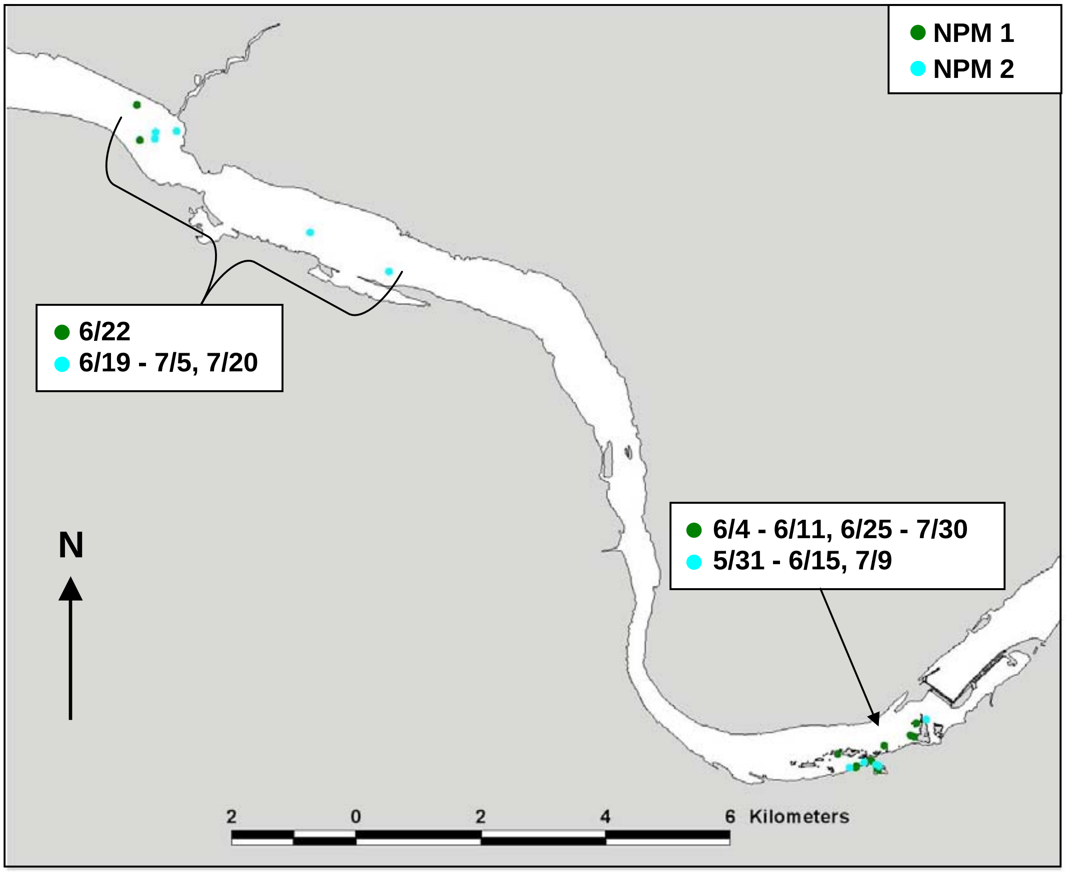


Figure 15. Large-scale movements of two radio-tagged northern pikeminnow (NPM) released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. Groups of points are labeled with the corresponding dates fish were located within the area.

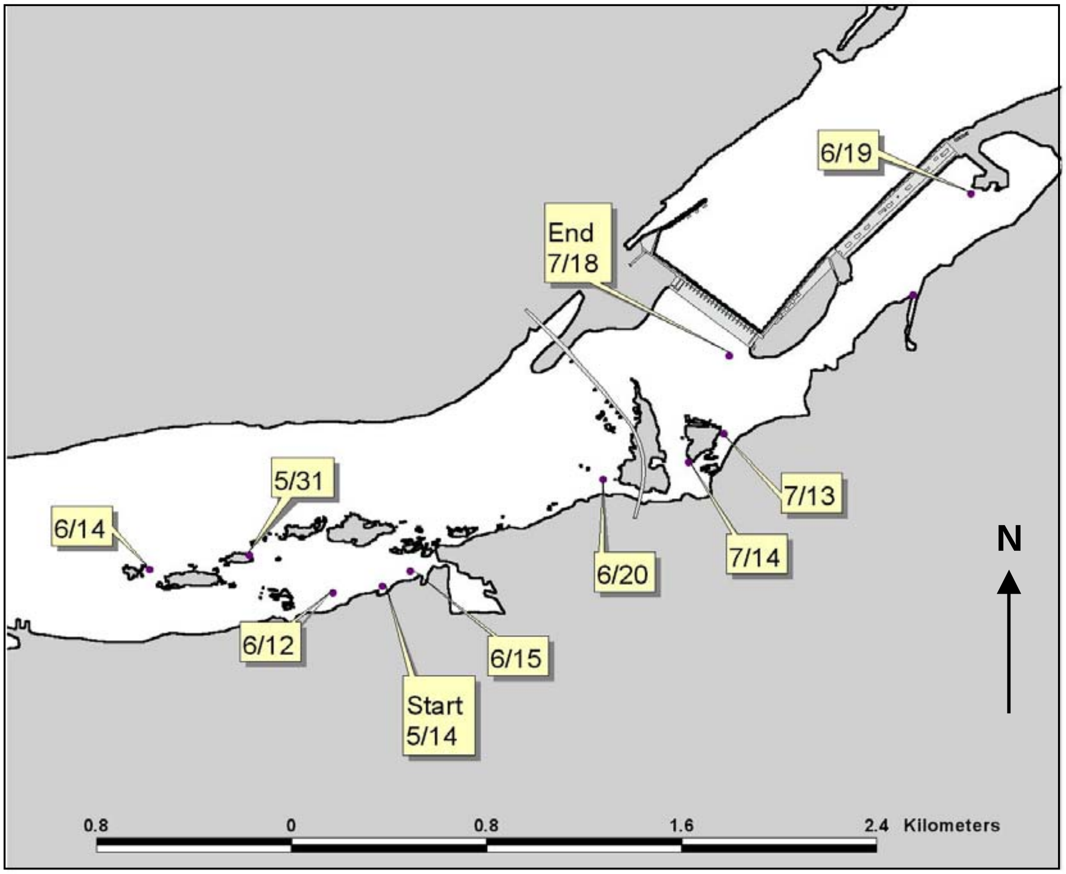


Figure 16. Travel path of a radio-tagged northern pikeminnow released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. Each point is labeled with the date of collection.

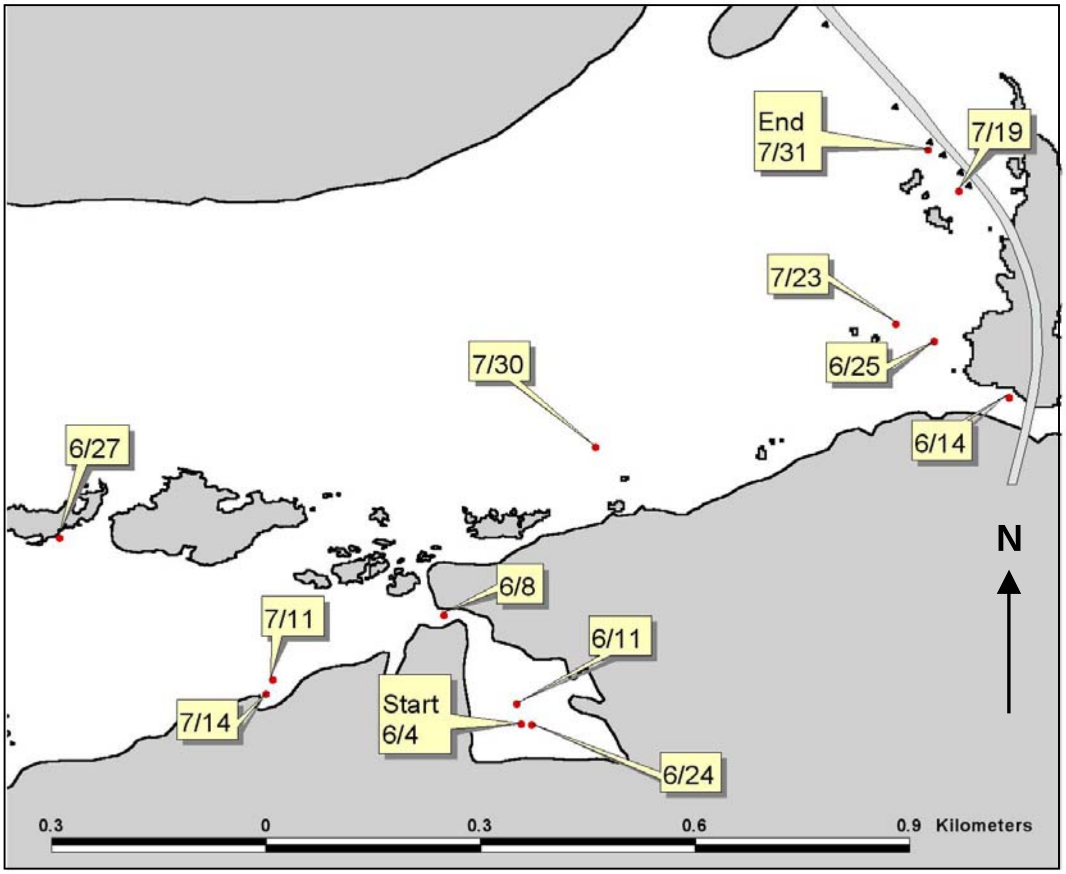


Figure 17. Travel path of a radio-tagged northern pikeminnow released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. Each point is labeled with the date of collection.

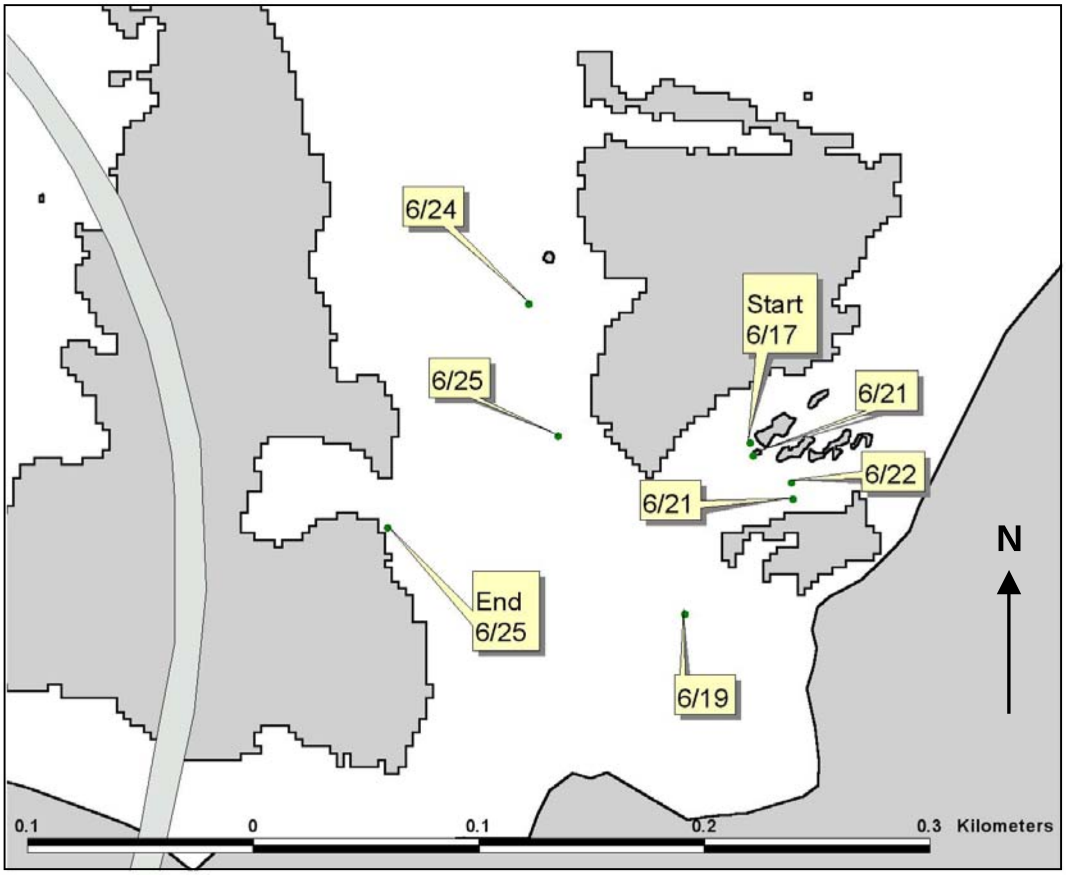


Figure 18. Travel path of a radio-tagged northern pikeminnow released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. Each point is labeled with the date of collection.

A χ^2 analysis of habitat indicates that NPM preferences were significantly different from the amount of habitat available within the study area ($\chi^2 = 59.44$, $P < 0.0001$; Table 5). Northern pikeminnow preferred bedrock to all other substrate types. Northern pikeminnow locations associated with bedrock (78.8%) were greater than expected given the amount of bedrock substrate available as habitat (61%). Cobble/gravel was avoided as a substrate type within the study area and was used less (2.7%) than expected by availability (24.9%). Boulder and sand/mud substrates were neither preferred nor avoided. Substrates at TDA are presented in Figure 19.

Table 5. Chi-square (χ^2) test for goodness-of-fit of northern pikeminnow substrate association to availability in The Dalles Dam tailrace, 2002. Maximum likelihood χ^2 (G^2) is included for comparison. Percentage association confidence intervals (95%) were calculated using a Bonferroni correction to alpha, and are presented with the confidence limits (CL).

Substrate	N	Availability (%)	Association (%)	% Association CL
Northern pikeminnow (χ^2 = 59.44, p <0.0001; G^2 = 73.74)				
Bedrock	175	61	79	71, 86
Boulder	5	1	2	0, 5
Cobble/gravel	6	25	3	0, 6
Sand/mud	36	13	16	9, 23

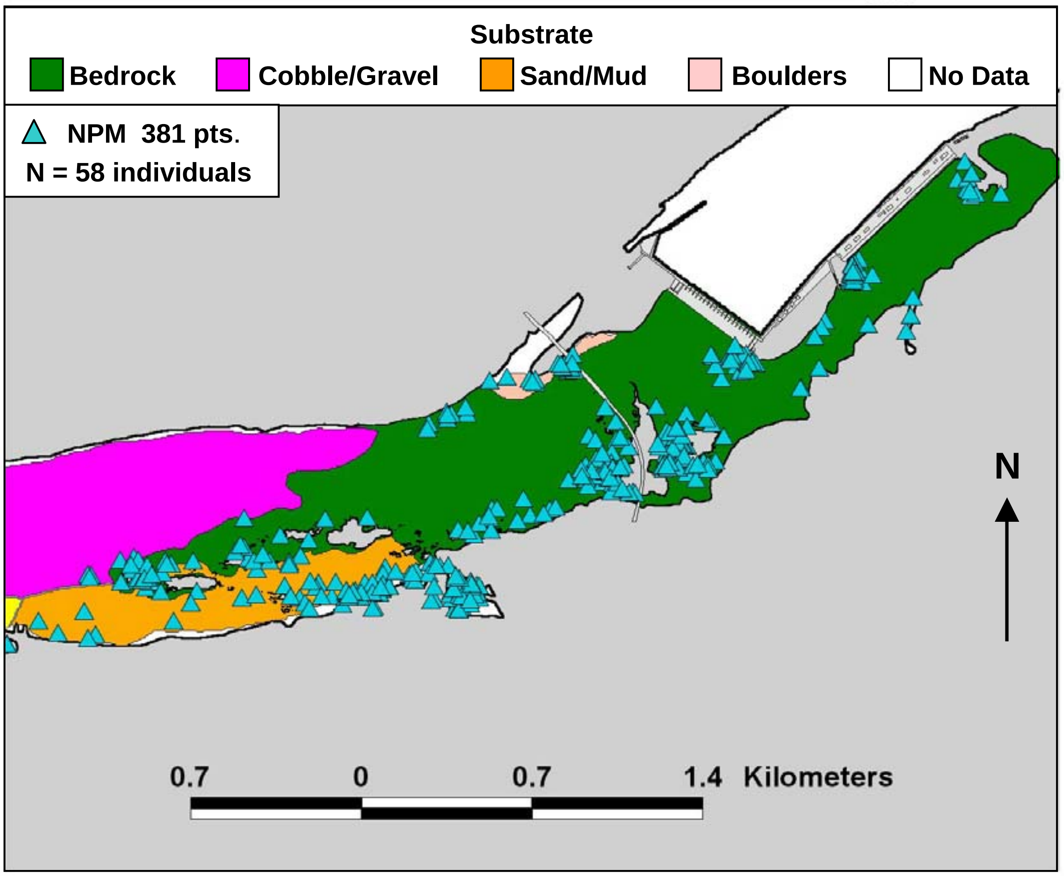


Figure 19. Locations of radio-tagged northern pikeminnow (NPM) and substrate types in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking.

Smallmouth Bass

During the study period seventy (97%) SMB were detected in the study area. These fish averaged 44.5 days (range: 1 d – 127 d) within the study area. Twelve radio-tagged SMB were detected within the study area at the end of the study (Figure 2). We positively identified 49 (65%) of the radio-tagged SMB outside of the study area using mobile tracking data. Smallmouth bass traveled downstream as far as 50 km and upstream to John Day Dam (Figure 20). Two SMB were detected traveling up tributaries. One was detected in the Deschutes River, 11 km and 25 km upstream from the mouth, in two consecutive weeks. A second fish was detected about 2 km upstream from the mouth of the Klickitat River. Three (6%) of the fish that left returned to the study area (Table 6). Two of the fish returned over 40 days later, after traveling 5.7 km and 36.2 km upstream. One SMB traveled 15.3 km downstream and returned to the study area almost 36 days later.

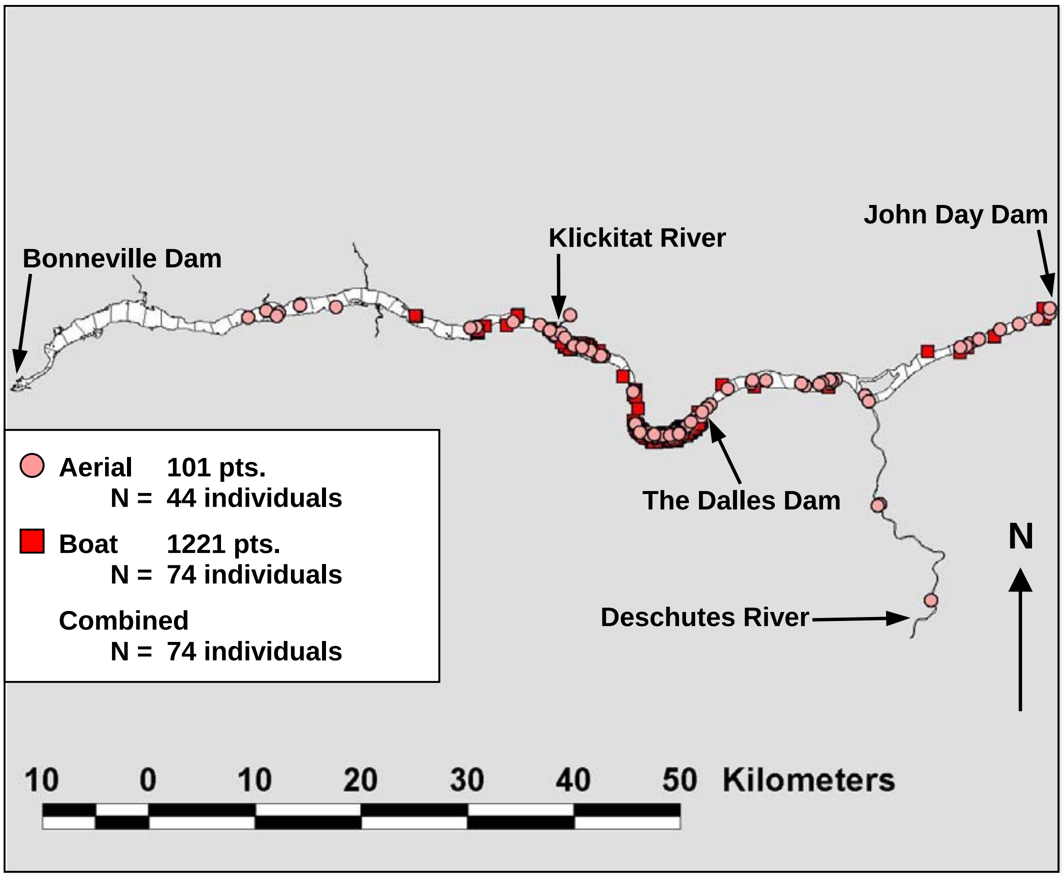


Figure 20. Locations of radio-tagged smallmouth bass (SMB) in the Columbia River and major tributaries between Bonneville and John Day dams, 2002. SMB were released at various sites in The Dalles Dam tailrace. Each point represents a fish location collected via aerial or boat tracking.

Table 6. Radio-tagged smallmouth bass (SMB) returning to The Dalles Dam tailrace, 2002. Location indicates the farthest detection from the tailrace during each event.

SMB ID	Location	Distance (km)	Days
51193	John Day Dam	36.2	43.2
57203	Horsethief Lake State Park	5.7	47.0
59209	Lyle	15.3	35.7

Boat tracking detections of SMB within the study area are presented in Figure 21. Smallmouth bass were most frequently detected in the basin island zone during all three study periods (Figure 22). Detections in the navlock zone were similar between study periods and, generally, accounted for about 20% of the detections in any given hour. Detections in the powerhouse zone remained between 15 and 20% during the spring and summer study periods, but increased to 20 – 30% during the post study period. Generally, BRZ and sluiceway zone use was less than 5% each during all three study periods. The frequency of zone use was similar regardless of time of day during all three study periods. Boat tracking detections by study period are presented in Figure 23. Smallmouth bass locations during day and night are presented in Figure 24.

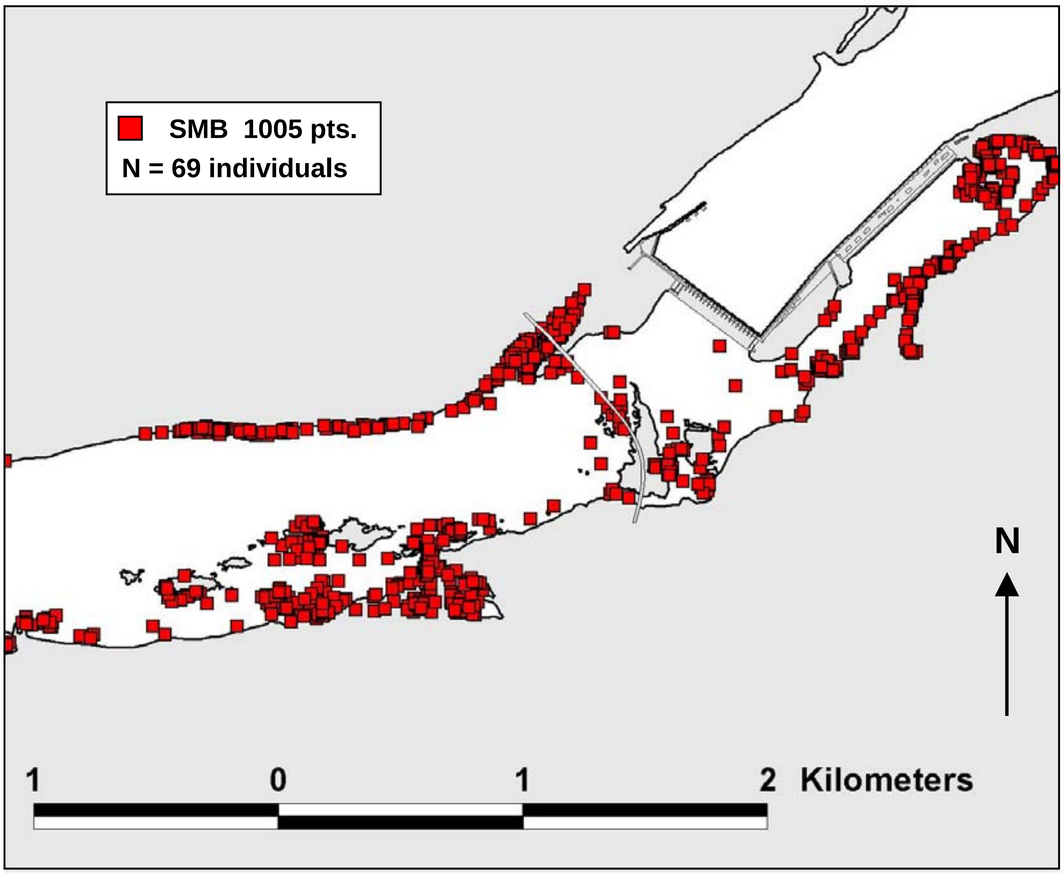


Figure 21. Locations of radio-tagged smallmouth bass (SMB) in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking over the entire season.

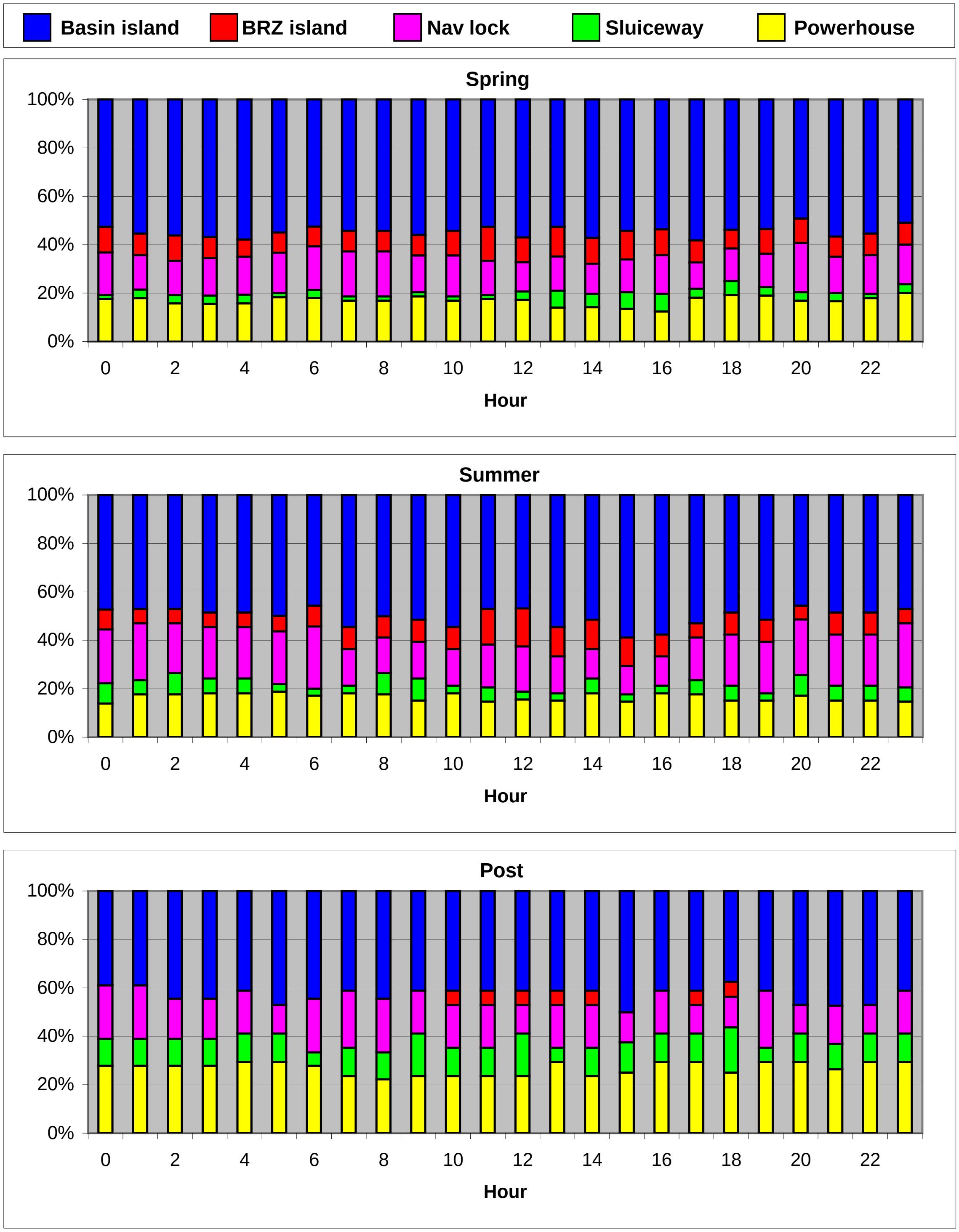


Figure 22. Observations of radio-tagged smallmouth bass (SMB) in The Dalles Dam tailrace during spring, summer, and post migration study periods, 2002. An observation represents the presence of an individual fish in a detection zone during an hour block. Each hour bar displays the percentage of total observations in each zone.

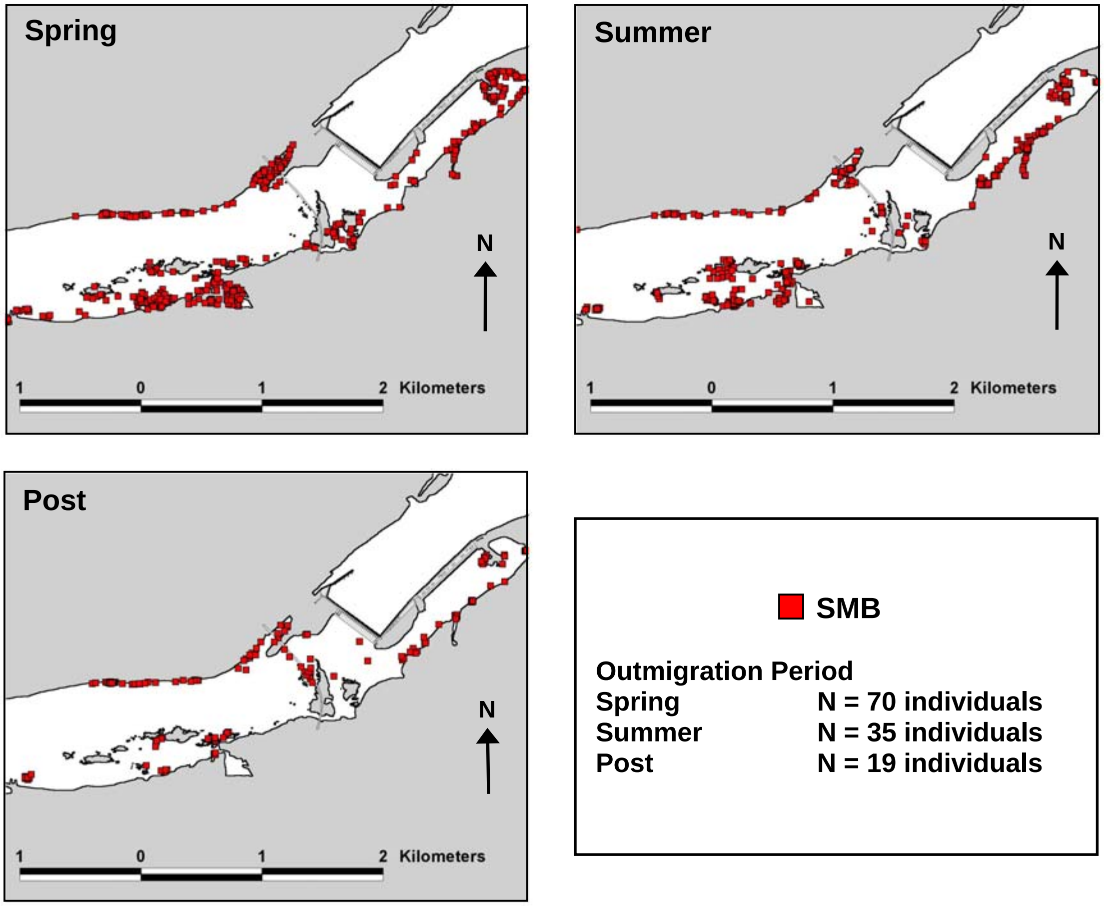


Figure 23. Locations of radio-tagged smallmouth bass (SMB) in the Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during spring, summer, or post outmigration study periods. Fish were monitored over multiple study periods. N represents the number of individual fish located. Spring locations in the tailrace total 245 points, representing 57 individuals. Summer locations in the tailrace total 139 points, representing 25 individuals. Locations in the tailrace total 178 points, representing 19 individuals during the post migration period.

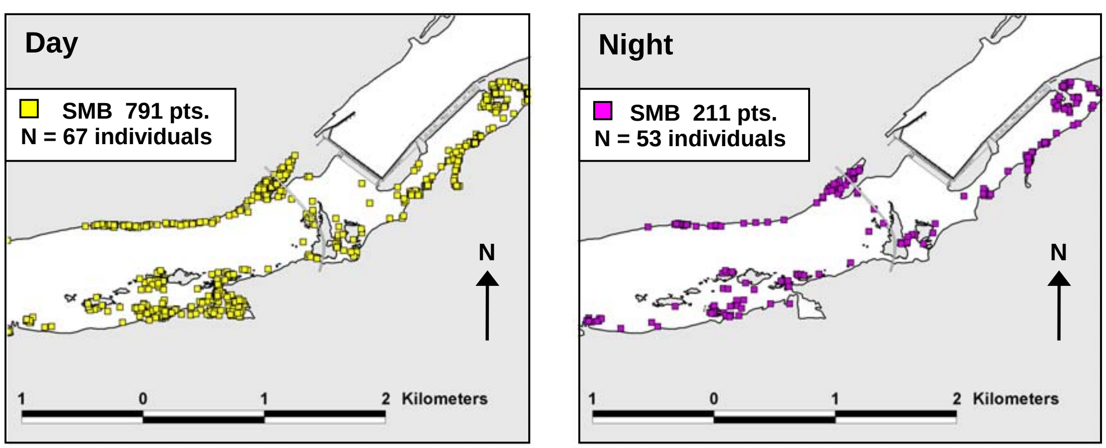


Figure 24. Locations of radio-tagged smallmouth bass (SMB) in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during either day or night.

Depths, velocities, and distances to structures and macrophytes corresponding to SMB location data during four turbine discharges and study periods are presented in Table 7. The median depth at fish location was 3.35 m (range 0.30 – 68.8 m). Median water velocity was 12.19 cm/s (range 0.00 – 176.8 cm/s). The median distance to a structure was 14.51 m (range 0.06 – 130.9 m). The median distance to macrophytes was 70.45 m (range 0.02 – 681.1 m). Median depths were not significantly different between turbine discharges, but were significantly different between study periods ($P < 0.03$; Table 7). Median water velocities at SMB locations were significantly different between turbine discharges ($P < 0.0003$) and study periods ($P < 0.0035$; Table 7). Median distances from structure were significantly different between turbine discharge conditions ($P < 0.0181$), but not between study periods. Median distances to macrophytes were not significantly different within turbine discharge or study period (Table 7). The bathymetry of the study area during the turbine discharge of 250 kcfs with associated SMB locations is presented in Figure 25. Velocities and SMB locations during the different turbine discharge conditions are presented in Figures 26 - 29.

Table 7. Depth, distance, and water velocity data assigned to radio-tagged smallmouth bass (SMB) locations in The Dalles Dam tailrace, 2002. Data is grouped by turbine discharge condition (TD) and study period (SP). Geographic Information System coverages were used to assign fish locations to river depth, water velocity, and distance data. Hydraulic modeling data of river depth and water velocity for 100, 150, 200, and 250 kcfs turbine discharge conditions were created by Pacific Northwest National Laboratory. Macrophyte coverage was mapped during a low flow year, 2001. An asterisk indicates medians between turbine discharge conditions or outmigration periods are significantly different.

TD (kcfs) SP	N	River depth (m)				Water velocity (cm/s)			
		Median	Mean	SE	Range	Median	Mean	SE	Range
100	211	3.66	4.77	0.39	0.30-56.39	6.10*	14.32	1.40	0.00-97.5
150	188	3.35	4.92	0.39	0.61-42.37	9.14*	15.61	1.41	0.00-109.7
200	130	3.35	5.88	0.60	1.22-32.92	12.19*	25.49	3.23	0.00-176.8
250	118	3.96	7.29	0.93	1.52-68.88	27.43*	40.14	3.41	0.00-167.6
Spring	258	3.81*	6.22	0.50	0.61-68.88	12.19*	22.39	1.90	0.00-167.6
Summer	260	3.05*	5.05	0.36	0.30-34.44	12.19*	24.31	1.93	0.00-176.8
Post	129	3.66*	4.95	0.57	0.30-56.39	6.10*	14.79	1.82	0.00-94.49
Overall	647	3.35	5.49	0.27	0.30-68.88	12.19	21.65	1.15	0.00-176.8

TD (kcfs) SP	N	Distance to structure (m)				Distance to macrophytes (m)			
		Median	Mean	SE	Range	Median	Mean	SE	Range
100	211	14.31*	20.39	1.34	0.47-88.7	80.11	230.58	17.62	0.10-681.1
150	188	15.21*	21.95	1.60	0.06-130.9	79.89	246.41	19.51	0.02-681.1
200	130	11.50*	15.38	1.29	0.06-99.9	58.47	235.28	23.34	0.12-681.0
250	118	15.06*	20.93	1.78	0.23-77.3	46.57	207.77	22.86	0.07-679.8
Spring	258	15.48	20.35	1.17	0.06-130.9	58.71	233.51	16.99	0.07-679.8
Summer	260	13.69	19.73	1.22	0.23-99.9	70.95	231.57	15.38	0.02-681.1
Post	129	13.73	19.53	1.80	0.47-81.7	108.96	229.66	22.74	0.10-681.1
Overall	648	14.51	19.93	0.77	0.06-130.9	70.45	231.96	10.21	0.02-681.1

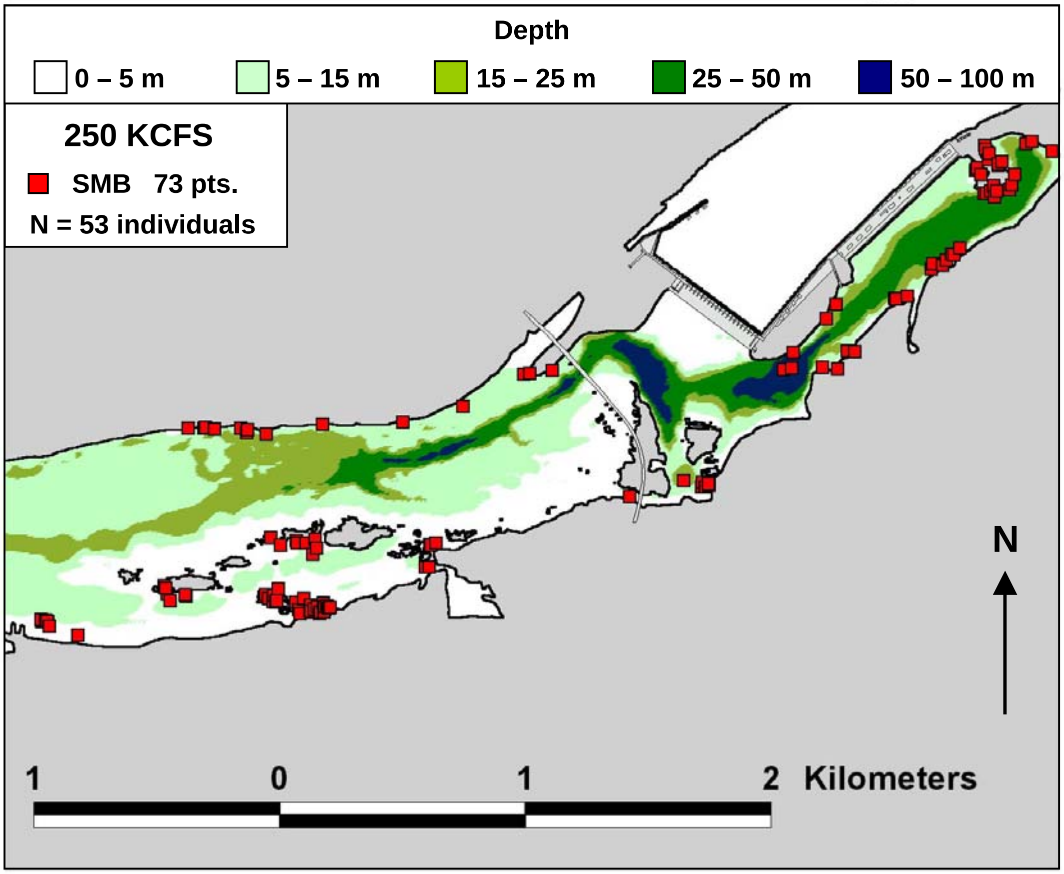


Figure 25. Locations of radio-tagged smallmouth bass (SMB) and river depths in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 250 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

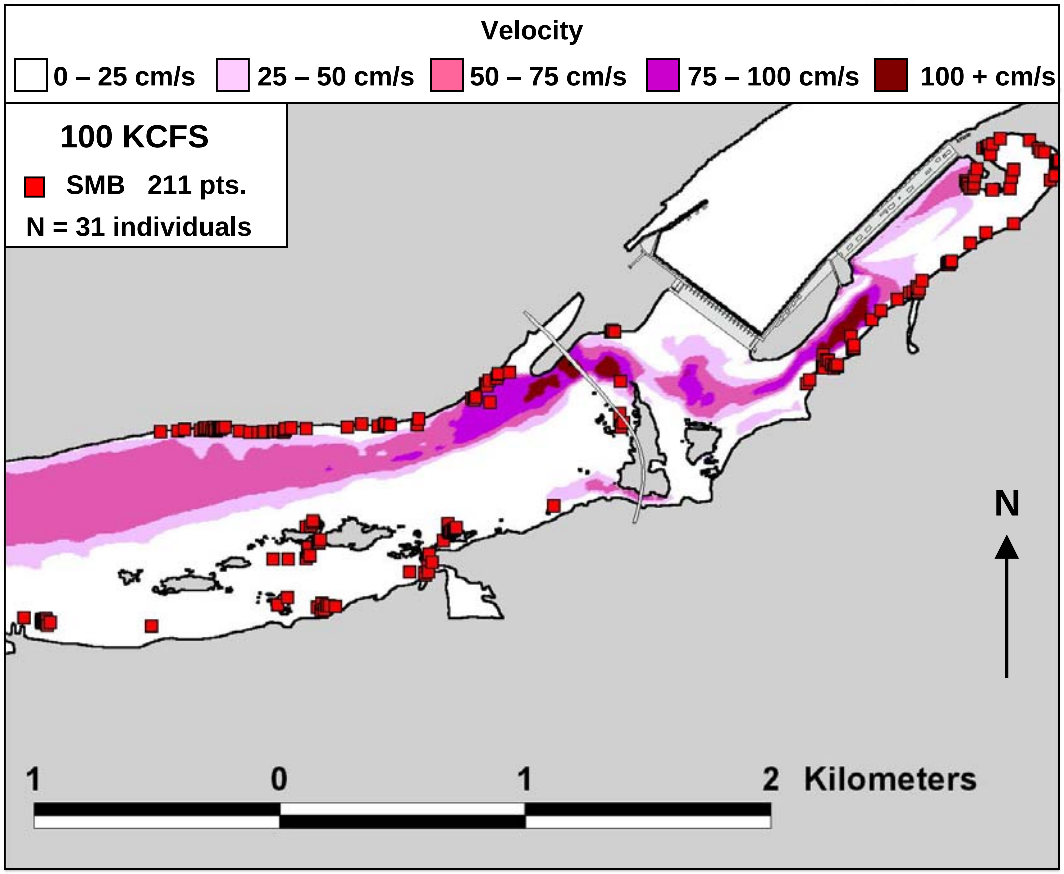


Figure 26. Locations of radio-tagged smallmouth bass (SMB) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 100 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

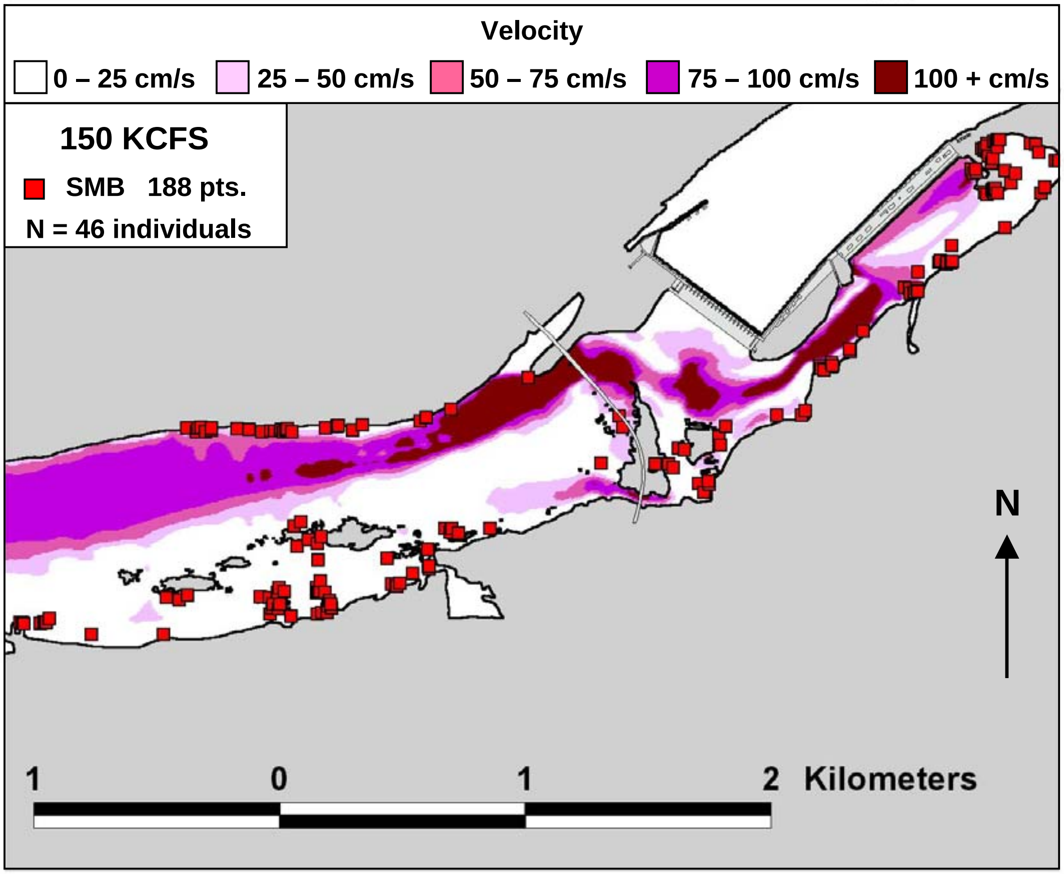


Figure 27. Locations of radio-tagged smallmouth bass (SMB) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 150 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

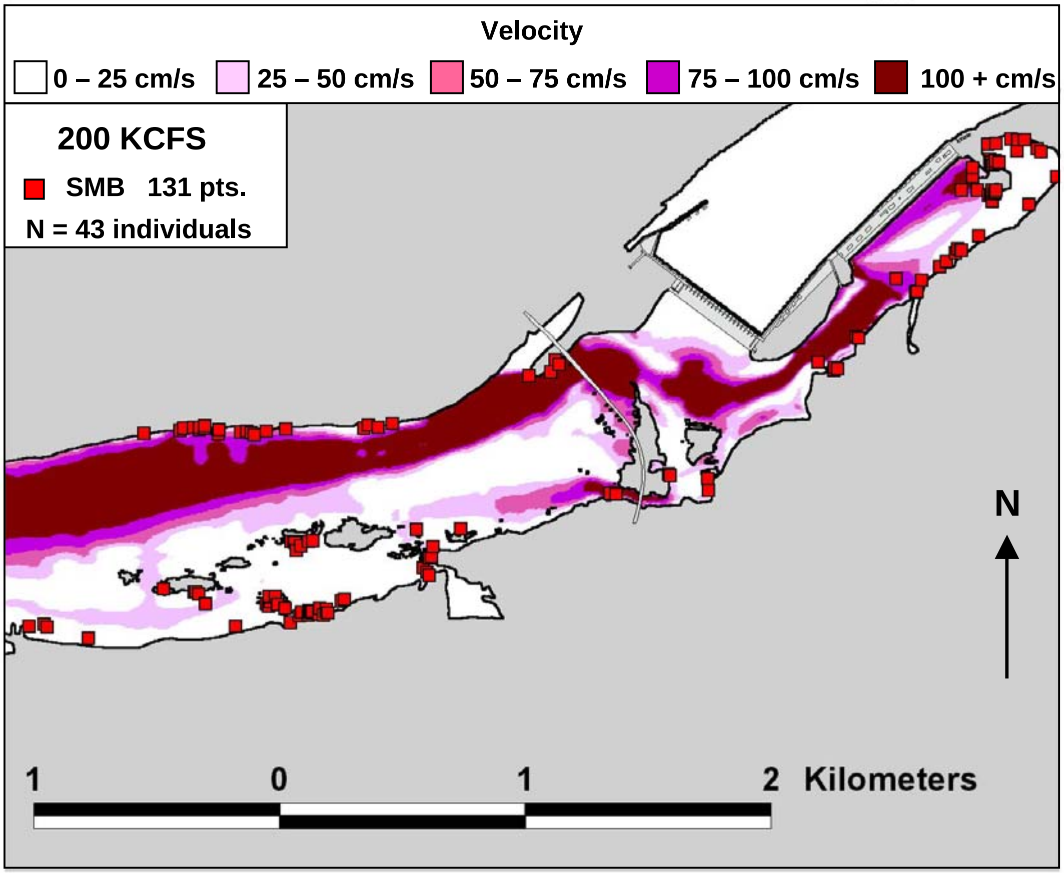


Figure 28. Locations of radio-tagged smallmouth bass (SMB) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 200 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

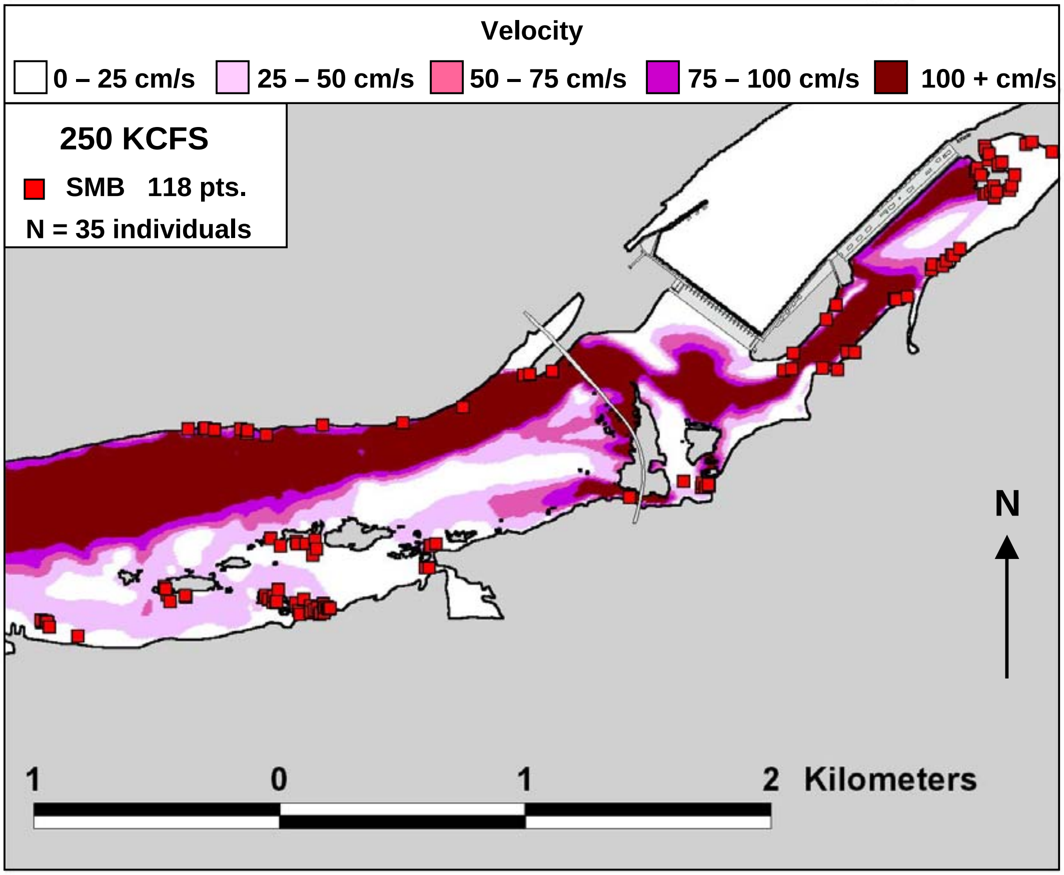


Figure 29. Locations of radio-tagged smallmouth bass (SMB) and river velocities in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking efforts during 250 kcfs turbine discharge conditions. Individual fish may be sampled in more than one flow regime.

Generally, SMB movements were classified as short distance (98.7%). Data reveals that individual fish did not stay within the confines of one zone. Individual SMB generally moved between zones about once per day (Figure 30). Travel rates and upstream/downstream movements are presented in Figure 31. Downstream and upstream movements were similar within each study period, while most movements occurred during the spring study period. Short distance movements were dependent upon study period, with more downstream (χ^2 = 1122.76, P < 0.0001) and upstream (χ^2 = 1151.07, P < 0.001) movements occurring during the spring. Most short distance movements were less than 0.6 km/h (74.8%). Long distance movements were also dependent upon study period. Most downstream (χ^2 = 11.06, P < 0.004) and upstream movements (χ^2 = 11.49, P < 0.0032) occurred during the summer. Seventy-five percent of the long distance movements had a travel rate of 0.2 km/h or less. Figures 32 - 35 show examples of single and multiple zone travel paths of radio-tagged SMB.

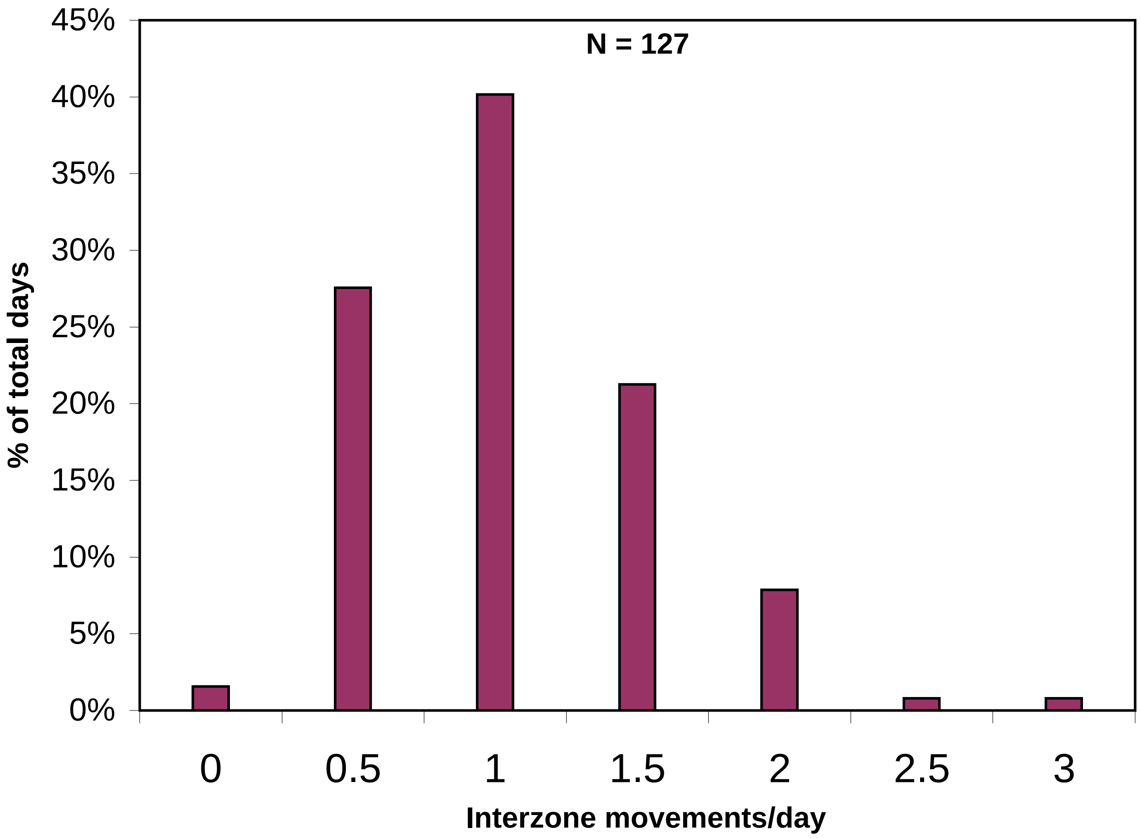


Figure 30. Average daily movement between detection zones by radio-tagged smallmouth bass (SMB) in The Dalles Dam tailrace, 2002. Detection zones were determined using fixed gear detection and boat locations. Interzone movements were calculated by summing SMB daily movements and dividing by the total number of fish detected that day.

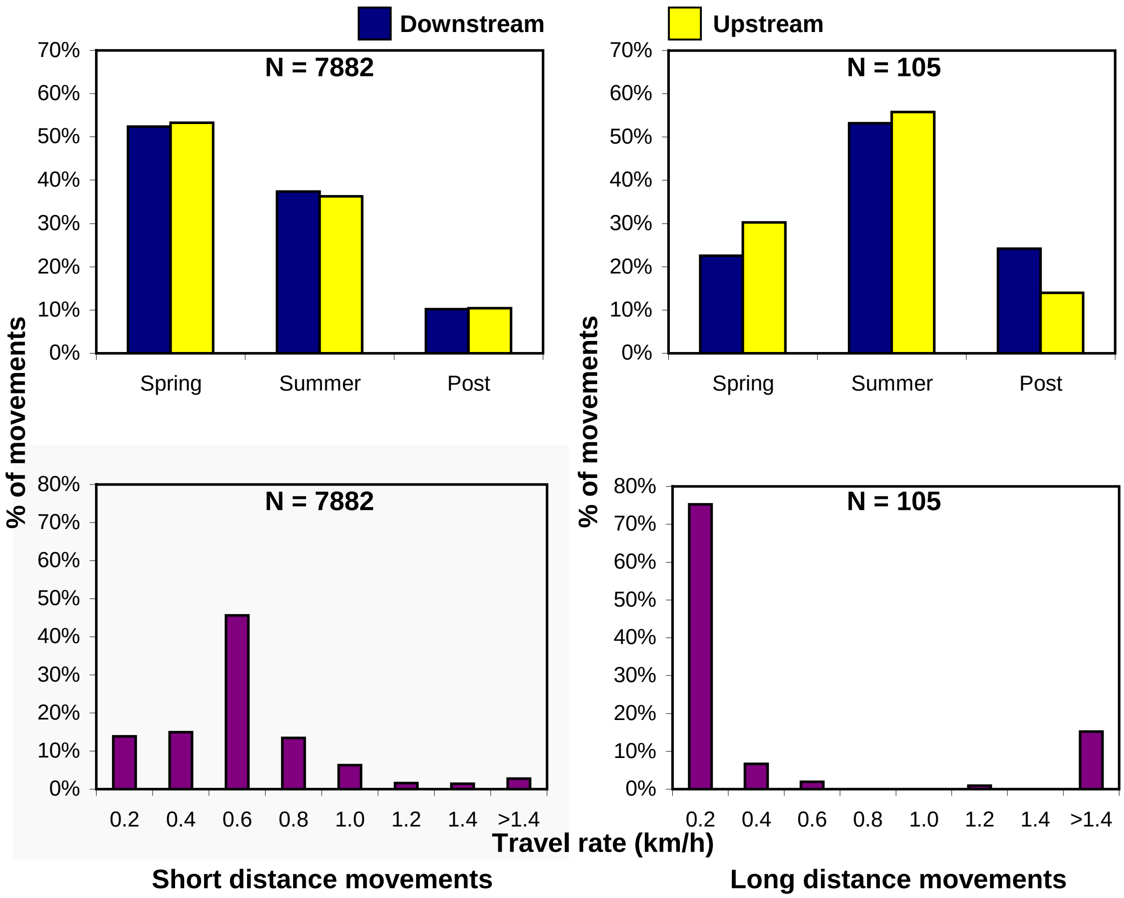


Figure 31. Direction and rate of movement of radio-tagged smallmouth bass (SMB) in the Columbia River, 2002. Movements are classified as short distance if fish locations were successively made within 2 km of each other and long distance if successive locations were greater than 2 km apart. Travel rates and directional movements were determined using fixed station detections, boat locations, and aerial locations. Each movement was given a travel rate based upon distance traveled and travel time.

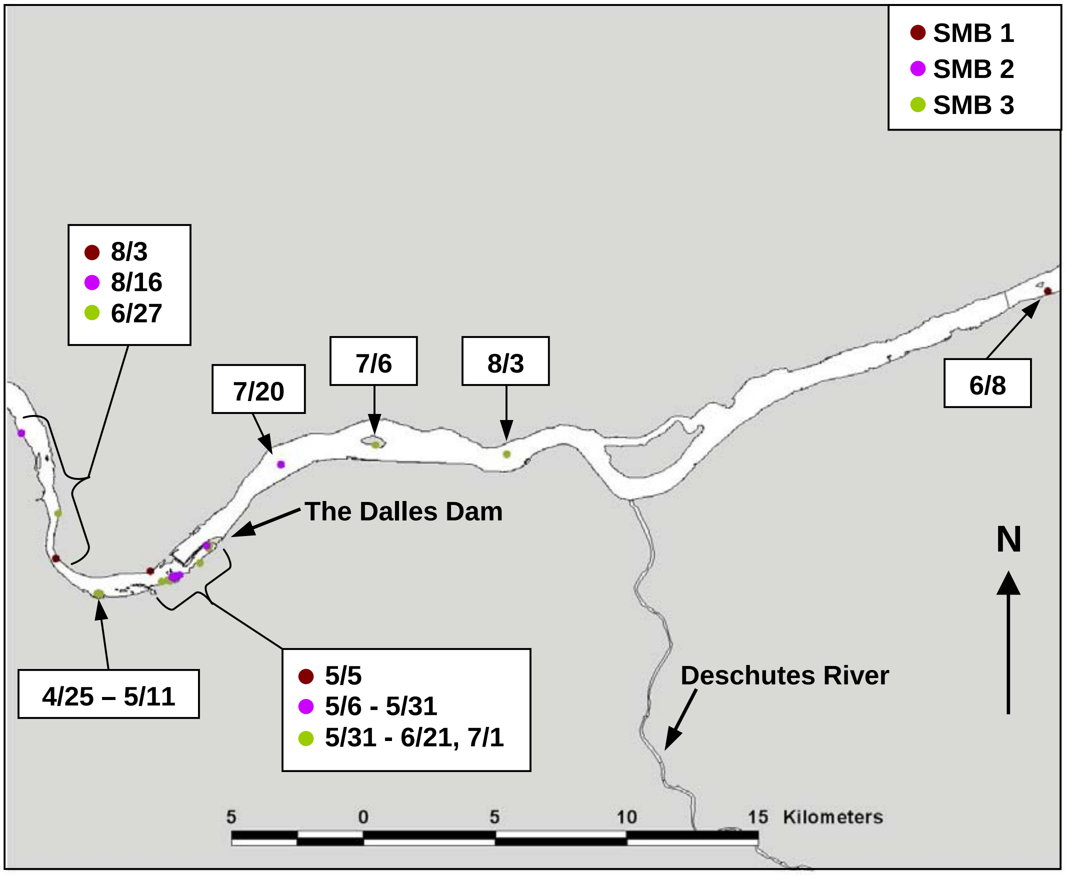


Figure 32. Large-scale movements of three radio-tagged smallmouth bass (SMB) released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. Groups of points are labeled with the corresponding dates fish were located within the area.

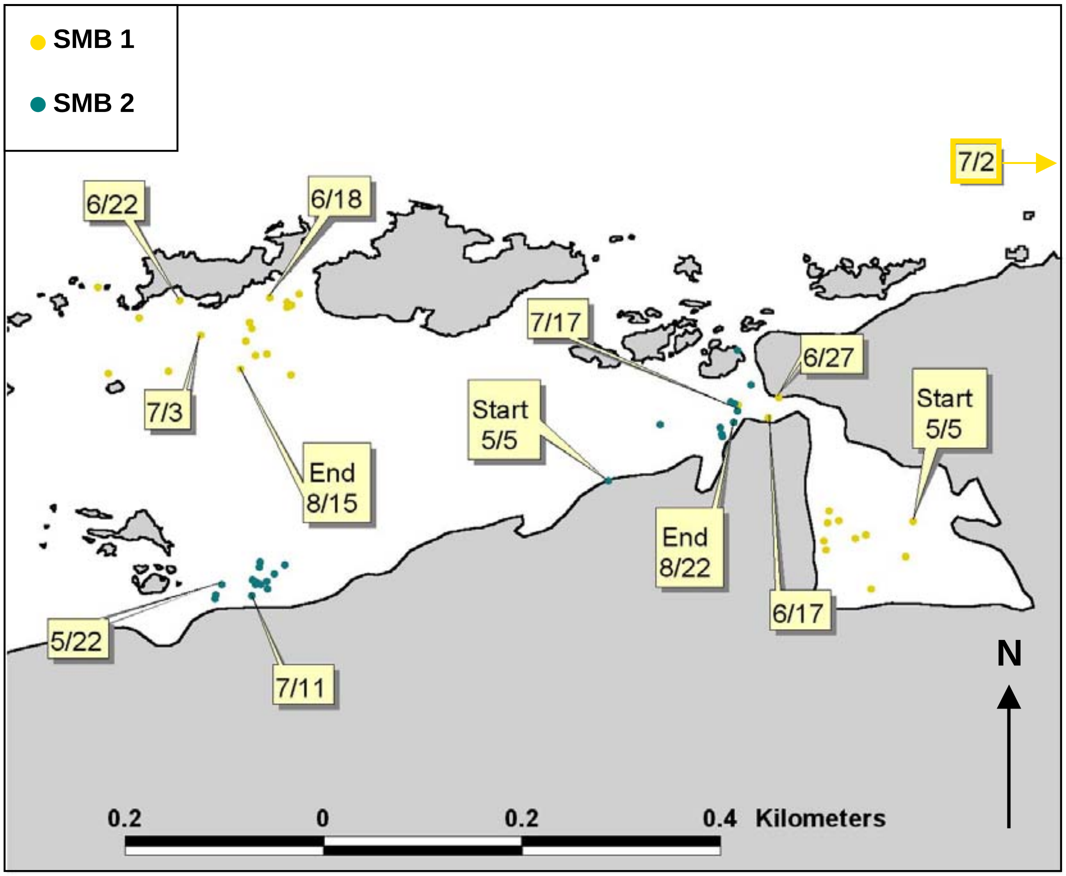


Figure 33. Travel paths of two radio-tagged smallmouth bass released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. First and last boat locations for each fish, and the locations before and after large movements, are labeled with the date of collection.

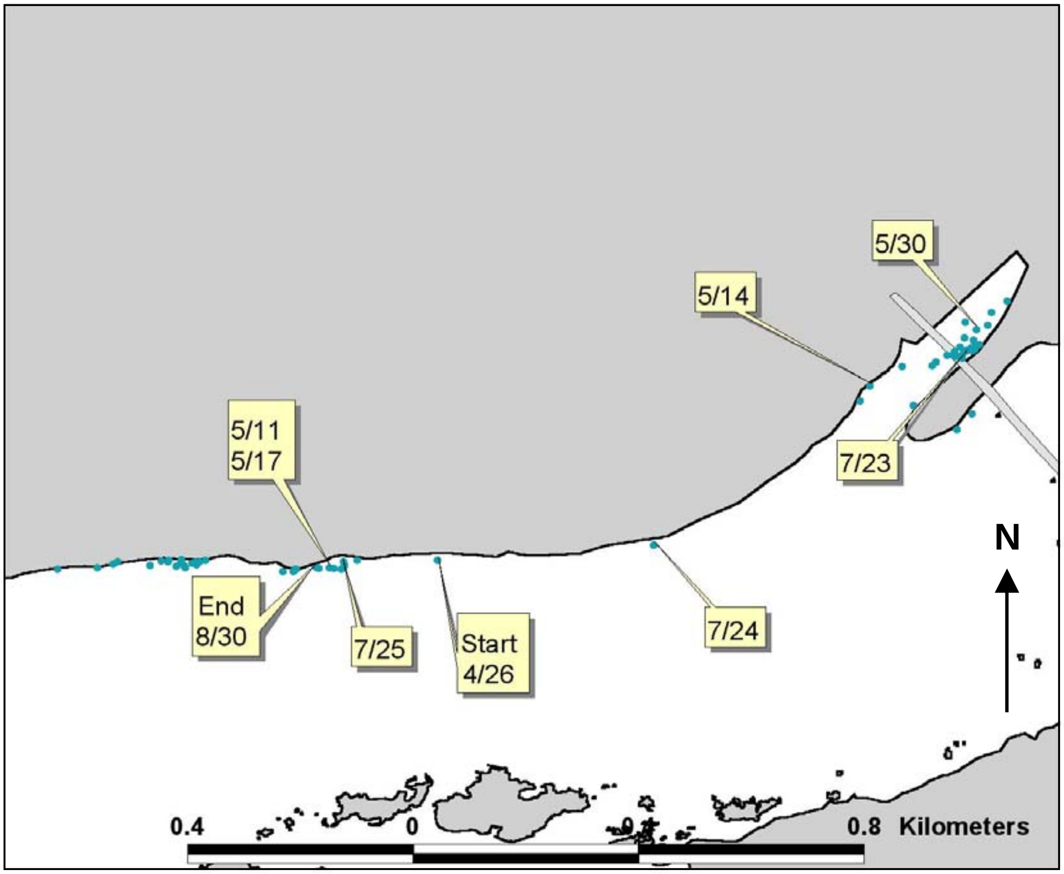


Figure 34. Travel path of a radio-tagged smallmouth bass released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. The first and last boat location and the locations before and after large movements are labeled with the date of collection.

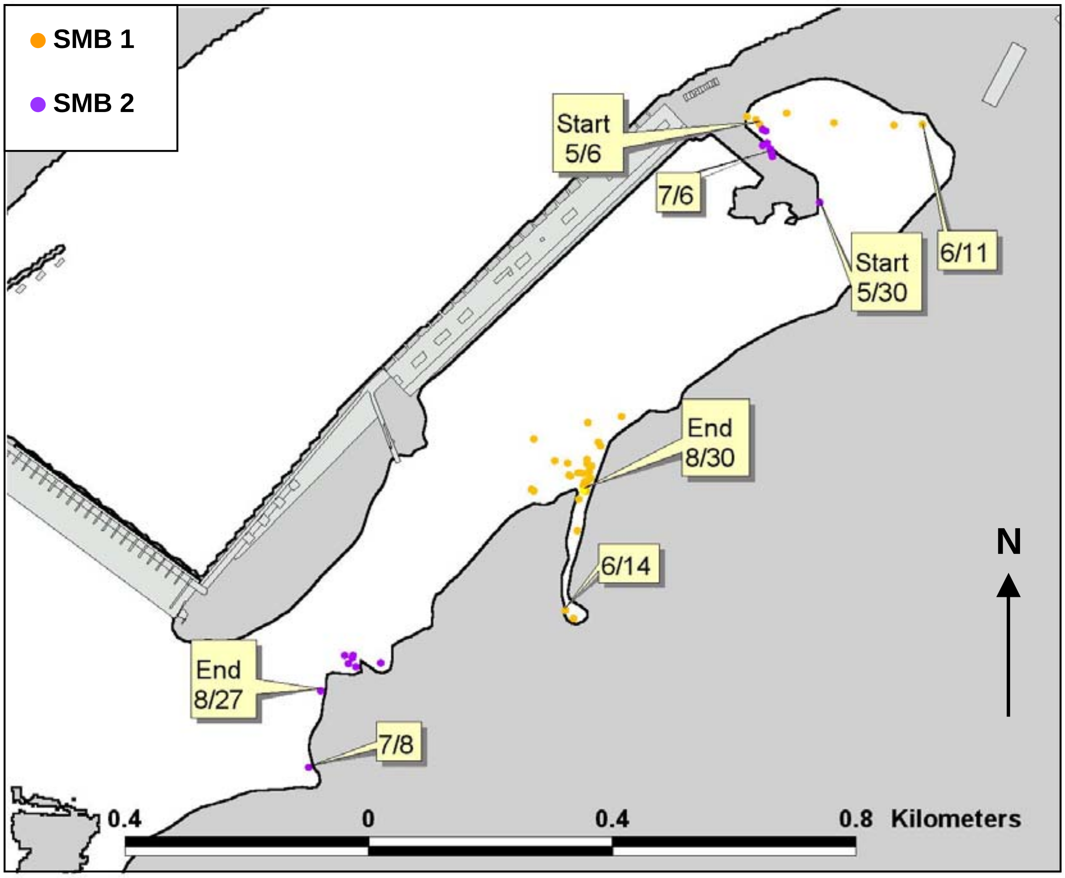


Figure 35. Travel paths of two radio-tagged smallmouth bass released in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking. First and last boat locations for each fish, and the locations before and after large movements, are labeled with the date of collection.

A χ^2 analysis of habitat indicates that SMB preferences were significantly different from the amount of habitat available within the study area ($\chi^2 = 125.59$, $P < 0.0001$; Table 8). Smallmouth bass use of bedrock was greater than all other substrate types, but the association with bedrock (61.7%) was similar to the availability of bedrock (61.0%). Smallmouth bass locations associated sand/mud (32.2%) were greater than expected given the amount available as habitat (12.9%). Cobble/gravel was avoided as a substrate type within the study area and was used less (4.3%)than expected by availability (24.9%). Boulder substrate was neither preferred nor avoided. Substrates and locations of SMB are presented in Figure 36.

Table 8. Chi-square (χ^2) test for goodness-of-fit of smallmouth bass substrate association to availability in The Dalles Dam tailrace, 2002. Maximum likelihood χ^2 (G^2) is included for comparison. Percentage association confidence intervals (95%) were calculated using a Bonferroni correction to alpha, and are presented with the confidence limits (CL).

Substrate	N	Availability (%)	Association (%)	% Association CL
Smallmouth bass ($\chi^2 = 125.59$, $p < 0.0001$; $G^2 = 168.09$)				
Bedrock	203	61	62	54, 69
Boulder	6	1	2	0, 4
Cobble/gravel	14	25	4	1, 7
Sand/mud	106	13	32	25, 40

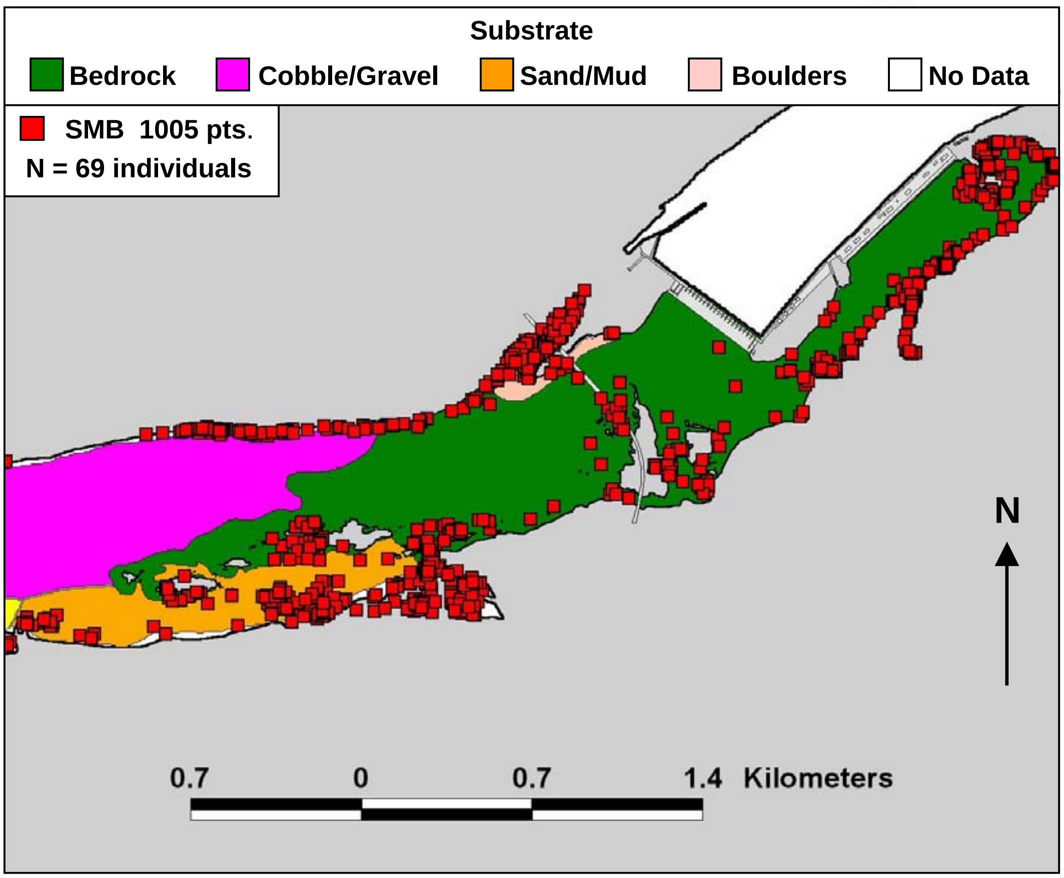


Figure 36. Locations of radio-tagged smallmouth bass (SMB) and substrate types in The Dalles Dam tailrace, 2002. Each point represents a fish location collected via boat tracking.

Juvenile Chinook Salmon

The median residence times of yearling Chinook salmon within the BRZ were significantly different between turbine discharge conditions (P < 0.0164, Table 9). These differences are likely due to the low sample sizes during turbine discharges of 200 and 250 kcfs. Median residence times of yearling Chinook salmon within the BRZ were not significantly different between day and night releases. Median residence time of yearling Chinook salmon within the BRZ was about 40 min (0.6 h; range 0.21 – 6.28 h), more than half the median residence time of 64 min (1.06 h, range 0.45 – 7.34 h) within the study area (Table 9). Median residence times within the study area were significantly different between turbine discharge conditions (P < 0.0055, Table 9). Residence times were not significantly different between day and night releases.

Table 9. Residence times of radio-tagged yearling Chinook salmon within The Dalles Dam tailrace, spring 2002. Fish were released through the ice-trash sluiceway. Residence times were calculated from the time of release until the last fixed gear detection at the tip of the navigation lock or the island in the Boat Restricted Zone (BRZ Exit, 0.7 km downriver of the dam) and from time of release to the last detection at the basin island or north shore exit sites (Basin Exit, 1.7 km downriver of the dam). An asterisk indicates median residence times between turbine discharge (TD) conditions are significantly different using Tukey's Studentized Range Test. There were no significant differences between day and night median residence times using the Wilcoxon two-sample test.

TD (kcfs)	BRZ exit (h)					Basin exit (h)				
	N	Median	Mean	SE	Range	N	Median	Mean	SE	Range
100	8	0.81*	1.07	0.28	0.66-3.02	13	1.39*	1.65	0.30	0.74-4.36
150	31	0.57*	1.06	0.21	0.25-5.81	40	1.04*	1.54	0.19	0.58-6.75
200	2	4.35*	4.35	1.93	2.42-6.28	3	2.96*	4.37	1.49	2.79-7.34
250	4	0.41*	0.39	0.08	0.21-0.55	7	0.54*	0.93	0.32	0.45-2.80
Day	26	0.59	1.33	0.32	0.21-6.28	38	0.96	1.74	0.27	0.45-7.34
Night	19	0.76	0.90	0.15	0.39-3.02	25	1.33	1.47	0.15	0.62-3.56
Overall	45	0.66	1.15	0.20	0.21-6.28	63	1.06	1.63	0.17	0.45-7.34

The median residence times of subyearling Chinook salmon within the BRZ were not significantly different between turbine discharge conditions or between day and night conditions (Table 10). Median residence time of subyearling Chinook salmon within the study area was nearly 73 min (1.21 h, range 0.60 – 9.43 h), but a majority (77%) of that residence time occurred within the BRZ (0.93 h, range 0.32 – 9.09 h; Table 10). Median residence times within the study area were significantly different between turbine discharge conditions (P < 0.0437, Table 10). Residence times were not significantly different between day and night releases.

Table 10. Residence times of radio-tagged subyearling Chinook salmon within The Dalles Dam tailrace, summer 2002. Fish were released through the ice-trash sluiceway. Residence times were calculated from the time of release until the last fixed gear detection at the tip of the navigation lock or the island in the Boat Restricted Zone (BRZ Exit, 0.7 km downriver of the dam) and from time of release to the last detection at the basin island or north shore exit sites (Basin Exit, 1.7 km downriver of the dam). An asterisk indicates median residence times between turbine discharge (TD) conditions are significantly different using Tukey's Studentized Range Test. There were no significant differences between day and night median residence times using the Wilcoxon two-sample test.

TD (kcfs)	BRZ exit (h)					Basin exit (h)				
	N	Median	Mean	SE	Range	N	Median	Mean	SE	Range
100	14	1.12	1.09	0.15	0.33-2.04	14	1.16*	1.47	0.17	0.86-2.79
150	28	0.88	1.46	0.33	0.32-9.09	31	1.36*	1.81	0.30	0.72-9.43
200	2	0.67	0.67	0.33	0.34-1.00	7	0.74*	0.94	0.16	0.60-1.75
250	2	0.99	0.99	0.56	0.43-1.53	1	2.15*	2.15	-	-
Day	31	1.00	1.45	0.29	0.33-9.09	34	1.34	1.82	0.27	0.78-9.43
Night	15	0.84	0.96	0.16	0.32-2.66	19	1.04	1.24	0.14	0.60-3.08
Overall	46	0.93	1.29	0.21	0.32-9.09	53	1.21	1.61	0.18	0.60-9.43

Yearling and subyearling Chinook salmon predominantly passed along the mid-channel and south shore of the BRZ. Boat tracking locations of juvenile Chinook salmon are presented in Figures 37 and 38. Mean distance to shore of CH1 was 62.0 m. Subyearling Chinook salmon migrated at a mean distance to shore of 58.0 m. Yearling and subyearling Chinook salmon had two general travel paths once reaching the BRZ island. One possible path was to follow the thalweg and exit the BRZ. The second path was along the south shore and resulted in entrainment in an eddy. Examples of BRZ passage are illustrated in Figure 39.

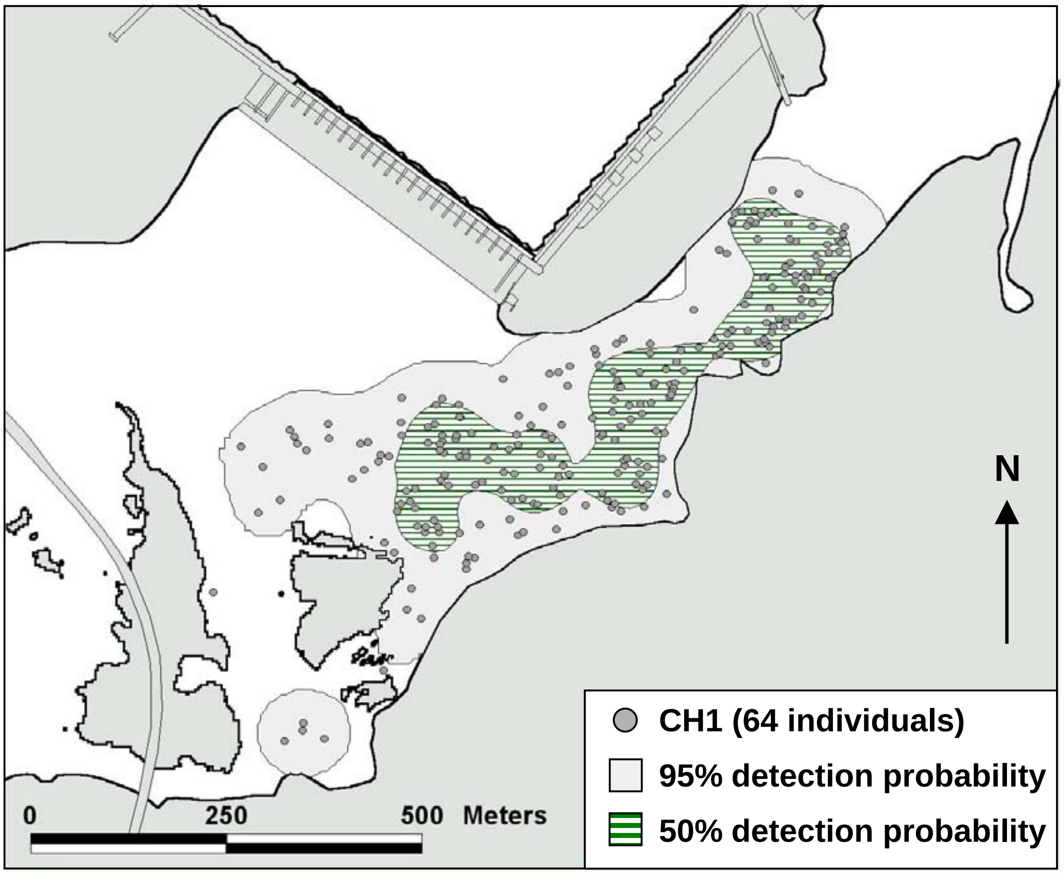


Figure 37. Locations of radio-tagged yearling Chinook salmon (CH1) in The Dalles Dam tailrace, spring 2002. CH1 were released through the ice-trash sluiceway. Each point represents a fish location collected via boat tracking. CH1 locations in the Boat Restricted Zone total 243 points, representing 64 individuals. The shaded area represents 95% probability that a CH0 will be detected within that area and is inclusive of the 50% probability (striped area).

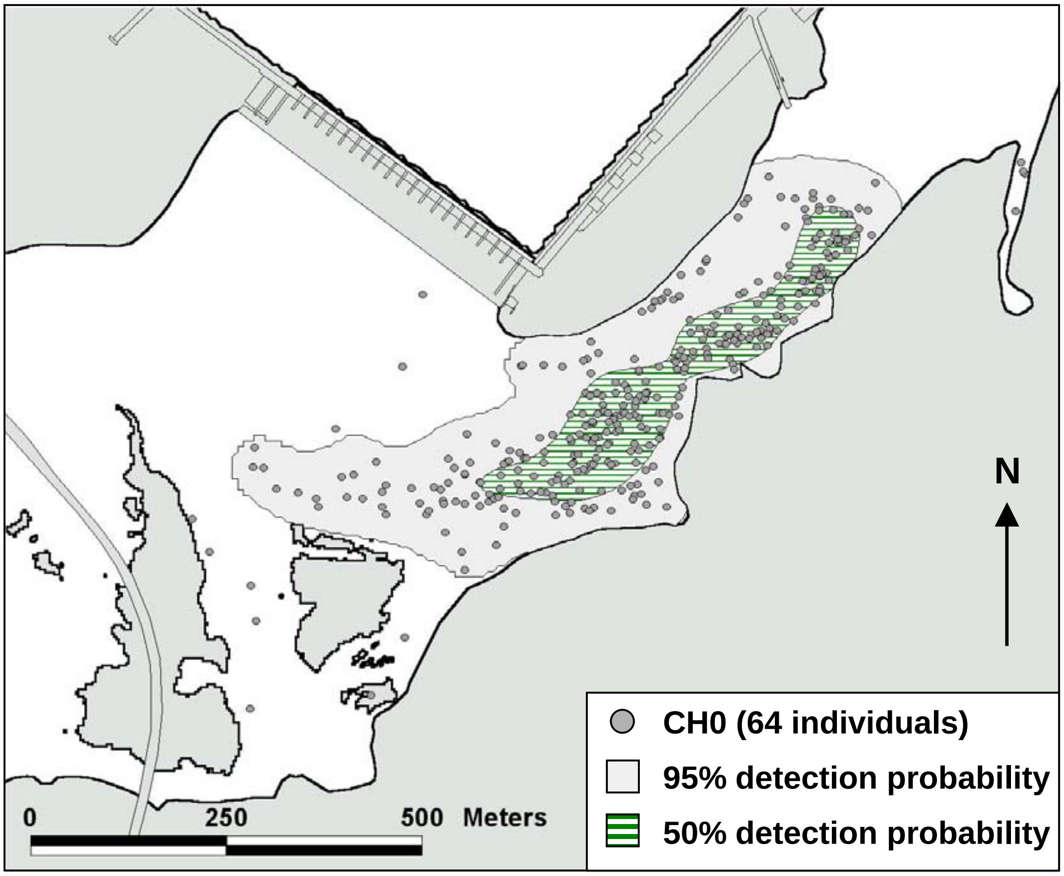
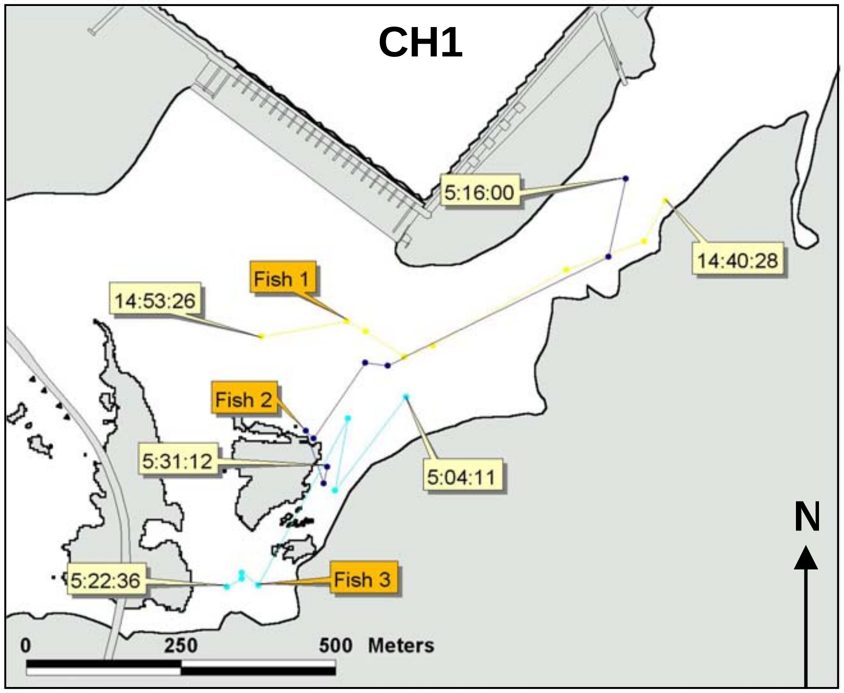


Figure 38. Locations of radio-tagged subyearling Chinook salmon (CH0) in The Dalles Dam tailrace, summer 2002. CH0 were released through the ice-trash sluiceway. Each point represents a fish location collected via boat tracking. CH0 locations in the Boat Restricted Zone total 344 points, representing 64 individual fish. The shaded area represents 95% probability that a CH0 will be detected within that area and is inclusive of the 50% probability (striped area).



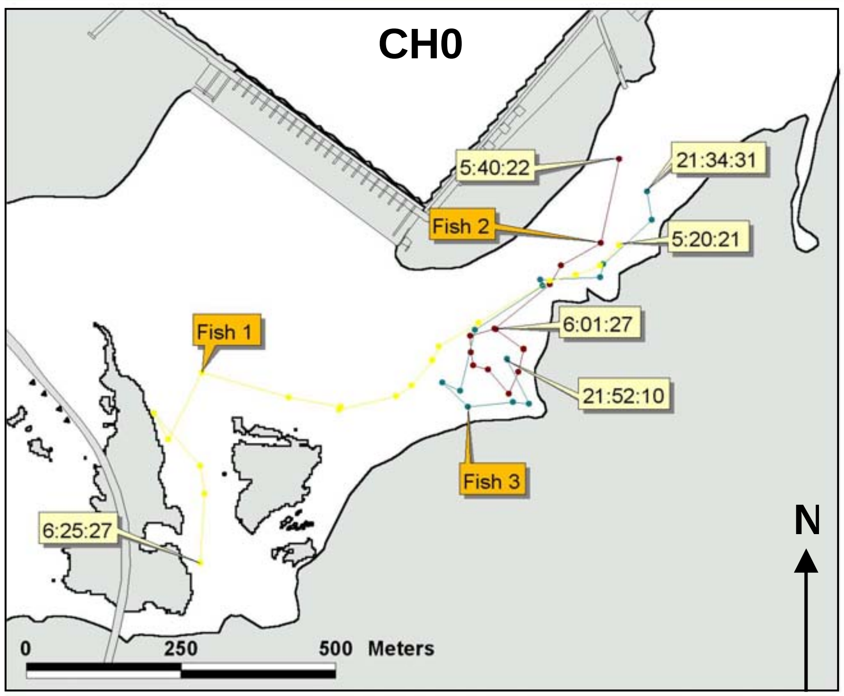


Figure 39. Travel paths of radio-tagged yearling (CH1) and subyearling (CH0) Chinook salmon released from The Dalles Dam sluiceway, 2002. Each point represents a fish location collected via boat tracking. Each path is labeled with the time of first and last location.

Northern pikeminnow and SMB locations during the release of CH1 and CH0 are presented in Figures 40–41. During spring outmigration, two (2%) of the radio-tagged CH1 were involved in suspected predation events (Figure 42). Six (7%) of the radio-tagged CH0 were involved in suspected predation events (Figure 42). The locations of the juvenile Chinook salmon were recorded at least 24 hours after release. Radio-tagged juvenile Chinook salmon involved in suspected predation events were repeatedly detected for up to eight days after release. Repeat detections occurred in or near the areas of first detection seen in Figure 42.

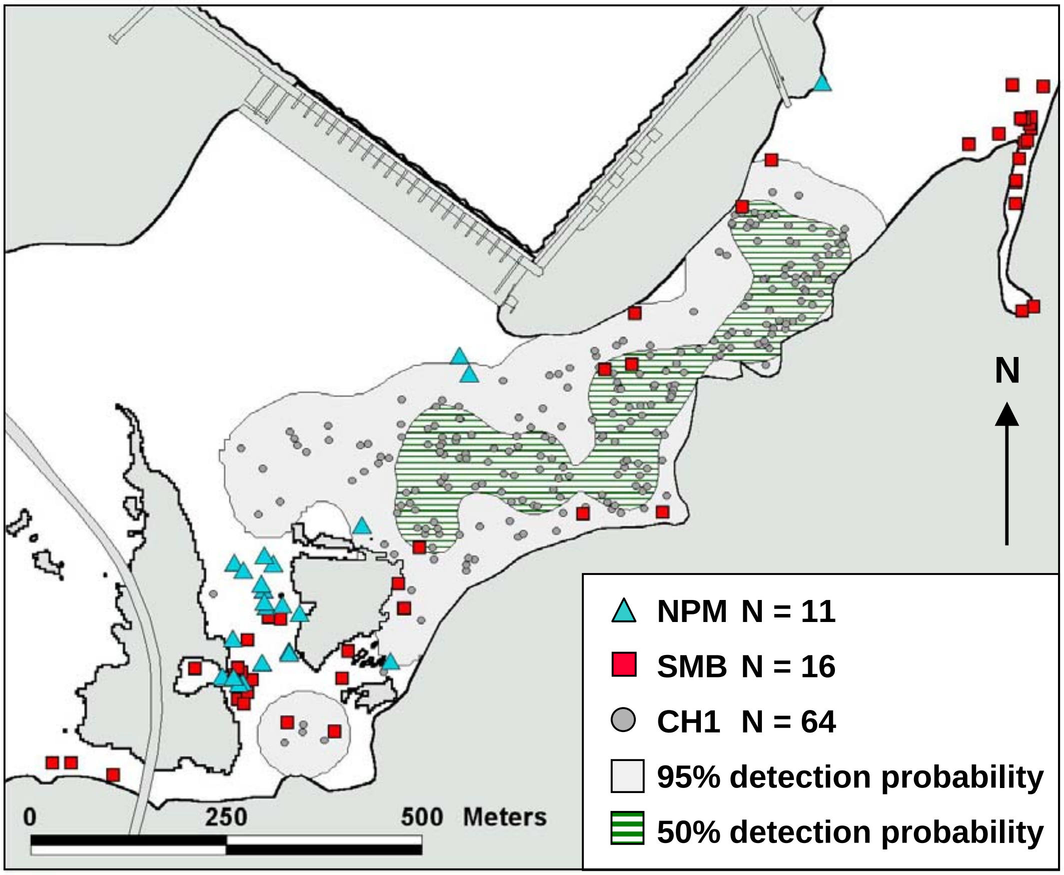


Figure 40. Locations of radio-tagged northern pikeminnow (NPM), smallmouth bass (SMB), and yearling Chinook salmon (CH1) in The Dalles Dam tailrace, between May 9 and June 1, 2002. NPM and SMB were released throughout The Dalles Dam tailrace and CH1 were released through the ice-trash sluiceway. Each point represents a fish location collected via boat tracking. NPM locations in the Boat Restricted Zone total 24 points, representing 11 individuals. N represents the number of individual fish located. SMB locations in the boat restricted zone total 48 points, representing 16 individuals. CH1 locations total 243 points, representing 64 individuals. The shaded area represents 95% probability that a CH0 will be detected within that area and is inclusive of the 50% probability (striped area).

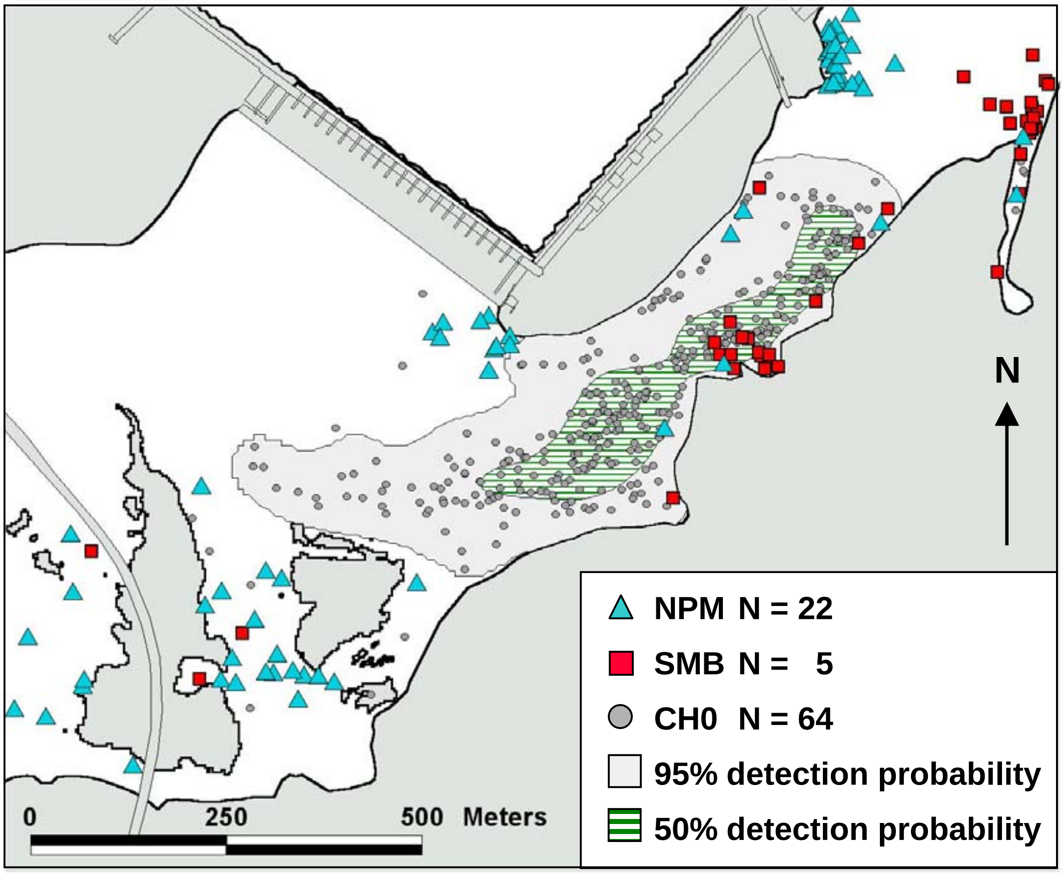


Figure 41. Locations of radio-tagged northern pikeminnow (NPM), smallmouth bass (SMB), and subyearling Chinook salmon (CH0) in The Dalles Dam tailrace, between June 29 and July 21, 2002. NPM and SMB were released throughout The Dalles Dam tailrace and CH0 were released through the ice-trash sluiceway. Each point represents a fish location collected via boat tracking. N represents the number of individual fish located. NPM locations in the Boat Restricted Zone total 72 points, representing 22 individuals. SMB locations in the Boat Restricted Zone total 41 points, representing 5 individuals. CH0 locations total 344 points, representing 64 individual fish. The shaded area represents 95% probability that a CH0 will be detected within that area and is inclusive of the 50% probability (striped area).

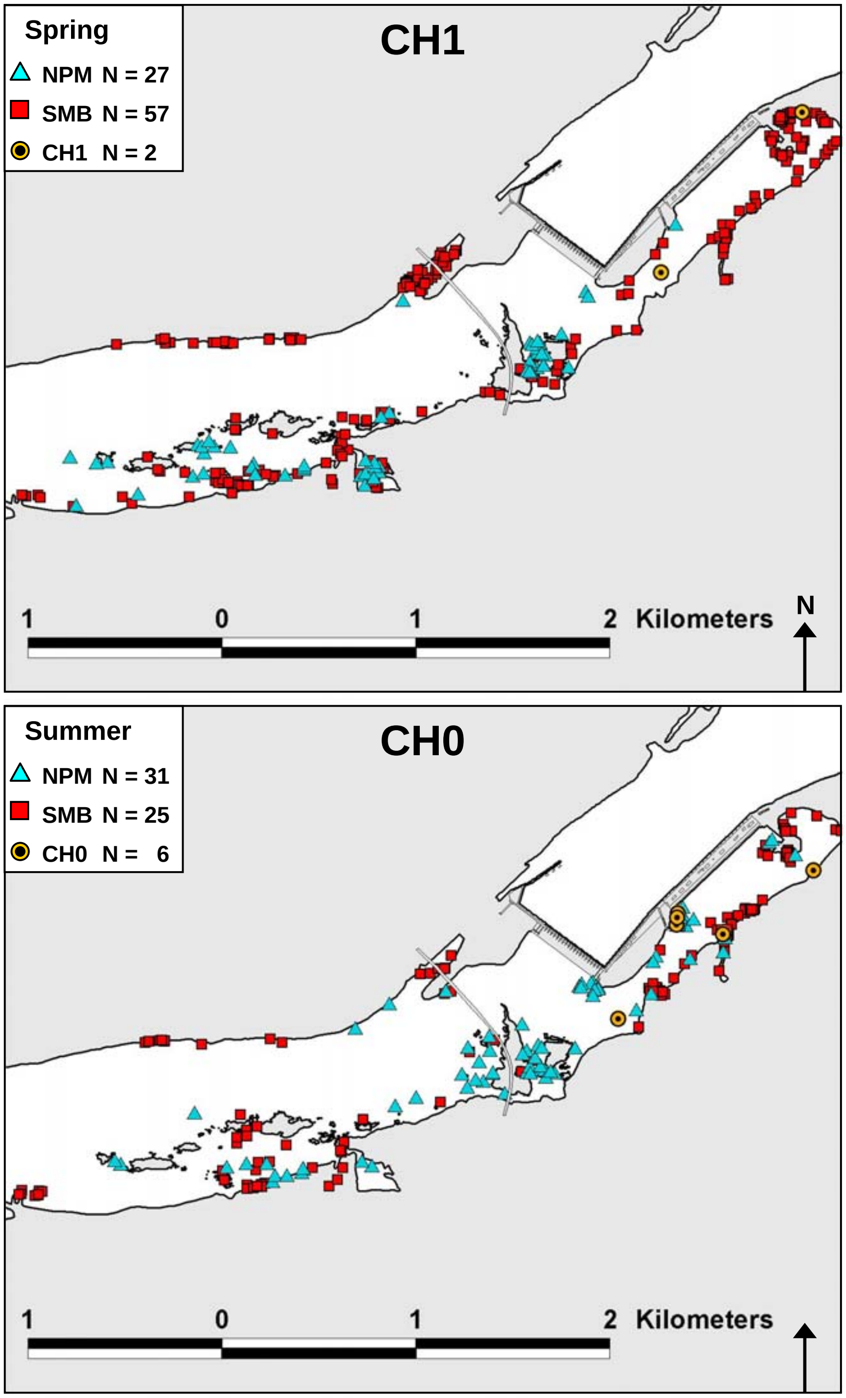


Figure 42. Locations of radio-tagged northern pikeminnow (NPM), smallmouth bass (SMB), and depredated yearling (CH1) and subyearling (CH0) Chinook salmon in The Dalles Dam tailrace, spring and summer 2002. NPM and SMB were released at various sites in The Dalles Dam tailrace. Each point represents a fish location collected via boat tracking. N represents the number of individual fish detected. CH1 and CH0 were considered depredated if located 24 hours after release.

Discussion

Radio-tagged predators seemed to recover well from surgery, as most predators (96%) were detected by at least one tracking method. An attempt was made at the end of the season to recover predators specifically for an inspection of tagging effects. One fish was recovered and upon external examination appeared to have no ill effects from surgery. In addition, 6% of our tags were returned by anglers implying that radio-tagged fish were actively feeding. Upstream movements of fish as far as JDA are a further indication of recovery.

We were not able to collect and tag as many predators early in the season as planned, especially NPM, so data describe predator movements only for the latter half of the spring outmigration of juvenile salmonids and through the summer. The number of juvenile salmonids that we tagged and released through the sluiceway was also small, although the distribution and behavior of these fish appeared to be consistent with previous findings of juvenile Chinook salmon released through the sluiceway (Allen et al. 2000, Allen et al., in draft).

Detections of NPM within the study area suggested that distribution was not random. The distributions of NPM reported in this paper are similar to a 1993 - 1994 evaluation in The Dalles Dam tailrace (Martinelli and Shively 1997). The greatest proportion of detections occurred within the basin islands while the fewest detections were observed in the powerhouse zone. We noted some seasonal differences in detection frequencies of NPM among zones, with the highest proportion of occurrences in the basin and BRZ island zones during the spring and post study periods. The distributions of NPM detections were similar between zones during the summer period, when NPM occurrence in the tailrace was highest. Major areas of predation risk due to NPM were likely the basin and BRZ island zones, although we cannot say for sure where specific predation events occurred.

Detections within the study area suggest that SMB distribution was also not random, and certain conditions are preferred. The greatest proportion of detections occurred within the basin islands, with the Washington shore also being used very heavily. Fewer detections were recorded in the sluiceway zone than all other zones. The frequency of observations of SMB decreased in the basin and BRZ island zones through the tracking season (spring through summer), resulting in higher proportional use of other zones, although the shift was small (<8%). Areas of risk due to predation by SMB include the basin and BRZ islands, the navigation lock, the Washington shore below the navigation lock, and the Oregon shore across from the powerhouse.

The distributions of NPM and SMB within The Dalles Dam tailrace differed somewhat, suggesting these species may have different habitat preferences or responses to juvenile salmonid migration patterns. SMB tended to use the Washington shore much more extensively than NPM. Higher use of the Washington shore by SMB could expose salmonids that pass through the north spill gates to higher predation risk from SMB. There also appeared to be some separation of the predator species east of the sluiceway, with SMB more commonly detected than NPM. Both species were often found in the basin and BRZ island areas.

Throughout the field season, both NPM and SMB moved outside The Dalles Dam tailrace. Movements were highest during the summer study period compared to spring and post study periods. Northern pikeminnow movements during the summer period were likely related to spawning and rising river temperatures as suggested by Gadomski et al. (2001). Smallmouth bass movements during the summer period may be related to SMB returning to the main river channel after spawning in the backwaters of the tailrace as observed by Montgomery et al. (1980). Fewer movements were observed after the primary salmonid outmigration, but this may have been due to fewer predators in the study area. NPM generally moved between zones more often and had greater travel rates than SMB. This may indicate greater feeding activity or brief feeding bouts of NPM as suggested by Petersen and DeAngelis (1992) and Petersen (2001). Several fish left the study area and returned, but we were not able to discern if this movement was migratory in nature. When NPM left the study area, a higher proportion traveled downstream than upstream, contrary to results in Martinelli and Shively (1997), but the movement trend was less obvious for SMB.

Although eight predation events were observed on radio-tagged salmonids, none of the events appeared to involve radio-tagged predators. Our data suggests which of the predation events involved either NPM or SMB, based on locations of the depredated fish. However, we cannot identify the species of predator with certainty. None of the assumed predation events involved a tagged preyfish being eaten by a tagged predator, and the likelihood of detecting such an event was low.

Predation of radio-tagged juvenile salmonids increased between outmigration periods, supporting other evidence that consumption rates of NPM and SMB increase between spring and summer (Vigg et al. 1991). Temperature increases steadily during spring and summer, and the energetic demands of higher temperature could cause increased consumption rates by both predator species (Petersen and Ward 1999). Size-related vulnerability may partially explain this trend (Poe 1991), with the smaller subyearling Chinook salmon being more susceptible to predators than larger yearling Chinook salmon. Yearling Chinook salmon also spent less time within the BRZ (0.7 h) and the study area (1.1 h) than subyearling Chinook salmon (0.9 h and 1.2 h, respectively).

The Dalles Dam is the only dam on the lower Columbia River that lacks a JBS. Several researchers have advised that if a JBS were constructed at TDA that it should be located in water flow ≥ 100 cm/s, ≥ 75 m from structures, in water ≥ 10 m deep, and far from eddies, submerged cover, and littoral areas (Mesa and Olson 1993; Shively et al. 1996). Few of our detections of NPM and SMB fall outside this criteria (Figure 43). Similarly, Faler et al. (1988) found NPM avoided high flow associated with spill gate operation in the tailrace of McNary Dam. Helfman (1986) and Hoff (1991) established that predator association with cover is potentially important for several reasons, including protection from predators, attraction of forage fish, and predation advantage. In addition, physical cover has been found to be a major factor in habitat selection by SMB in free-flowing systems (Probst et al. 1984; Sechnick et al. 1986; Todd & Rabeni 1989; Bevelhimer 1996).

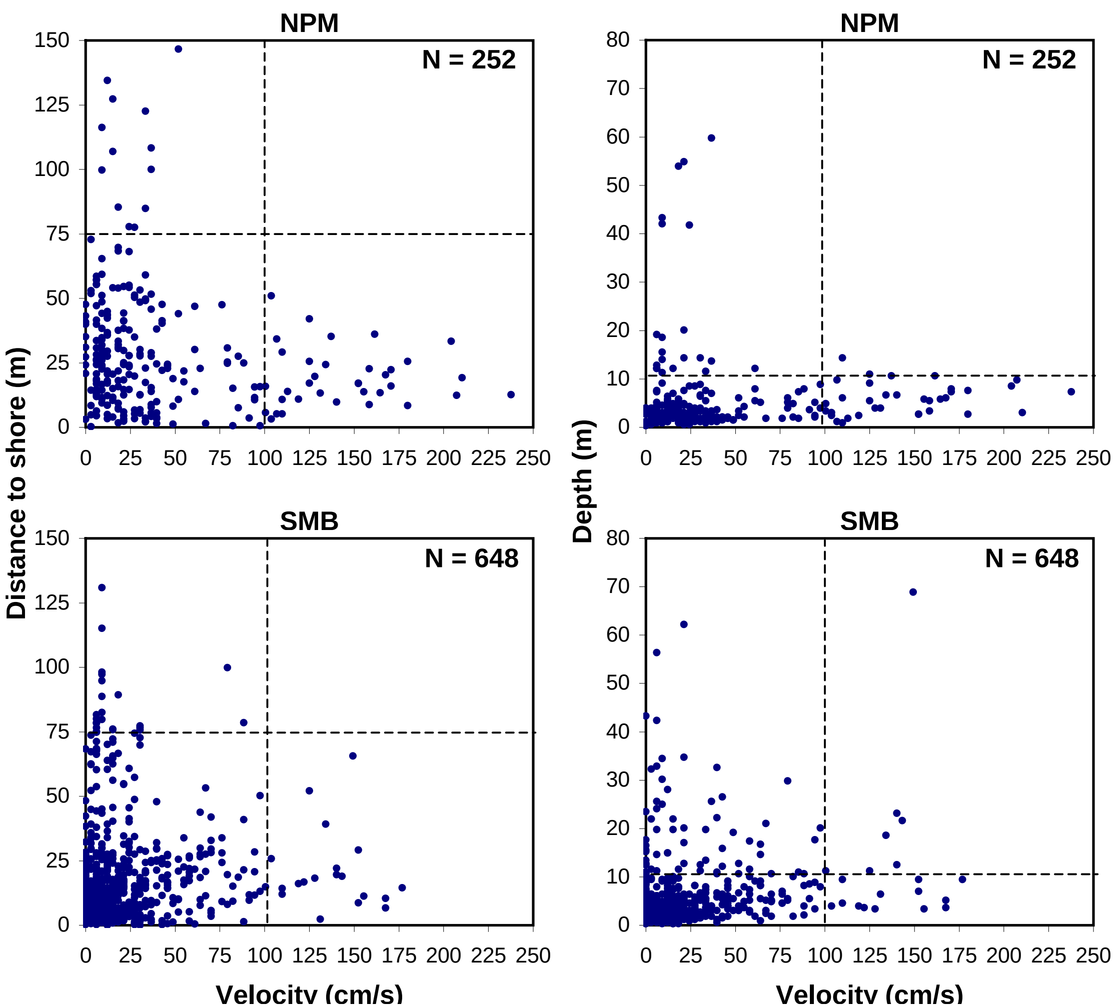


Figure 43. Scatter plots of distance from shore and river depth versus water velocity associated with locations of radio-tagged northern pikeminnow (NPM) and smallmouth bass (SMB) in the Dalles Dam tailrace, 2002. Dotted lines represent recommendations of juvenile bypass outfall locations.

Our research validates previous recommendations of JBS outfall placement as appropriate for reducing the predation risk of juvenile salmonids by NPM and SMB. We observed that radio-tagged predators were most frequently detected in habitats that were shallow (< 10 m), with low velocity (< 100 cm/s), near structure (< 75 m), and with bedrock or sand/mud substrate. These habitat conditions represent areas of high predator densities and possibly areas of high juvenile salmonid predation risk within the study area (Figure 44). The construction of a JBS based on these criteria may reduce the risk of mortality associated with predation by excluding predators from the outfall site and moving juvenile salmonids past areas of risk.

Figure 44. Conservative estimate of habitat preferences of predators within the tailrace. Criteria are based on locations of bedrock or sand/mud substrates, depth (< 10 m), flow (< 100 cm/s), and distance to shore or structure (<75 m).

The distributions of predators and juvenile salmonids within the tailrace of TDA could be used to estimate the "riskiness" of specific areas and to derive metrics for management. Resource selection functions are used to model the habitat preferences of fish and these functions have been linked to hydraulic models for predictive purposes (e.g., Guay et al. 2000; Tiffan et al. 2002; review in Petersen et al., in press). Spatial models of predators and prey, whose distributions are largely regulated by such variables as substrate type, water velocity, and water depth, could be used to identify specific areas or zones where predation risk is highest. Since such models would be developed in a spatial framework using a geographical information system, it would also be possible to derive tailrace-wide metrics that quantify predation risk under different operational scenarios. For example, it would be relatively easy to derive a metric that was the cumulative sum of all cells in the tailrace where the probability of predation or predator-prey encounter was above or below some criterion. Such a tool might be useful for making management decisions concerning bypass facilities, spillway operation, or other alternatives that have been discussed.

Acknowledgements

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